PREFACE.

Corrigenda Slip for the "Punjab Irrigation."

On page 51 the paragraph beginning "In 1916" and ending "Elsden" should be omitted altogether.

It is regrettable that this omission was not made earlier, even had I failed to make it in the manuscript.

On page 98, 3rd line from the bottom *substitute* "maturing" for watering in the expression "the watering of wheat."

N.B.—The statements made and the opinions expressed in this book are those of the author and are not to be interpreted as having the authority of the Punjab Government.

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PART I.

CHAPTER I.

Historical Introduction.

It is reasonable to suppose that irrigation has been practised for nearly as long as agriculture has given to men an increase of the kindly fruits of the earth.

In Egypt the King Menes is said to have irrigated from the Nile in 2700 B.C.

Egypt, China and Mesopotamia, *i. e.*, the valleys of the Euphrates and the Tigris are localities in which there is evidence that irrigation was practised.

In Spain irrigation has been practised for three thousand years.

In India irrigation must have been in vogue along the banks of the rivers as far back as in any of the countries mentioned.

In the Punjab, irrigation along the banks of the rivers must be of ancient origin, the efforts being largely individual.

There are the following canals to testify to later state enterprise :

The Western Jumna Canal.

The Hasli Canal from the Ravi, the forerunner of the present Bari Doab Canal.

Some canals in the Multan district.

THE WESTERN JUMNA CANAL.

At the annexation of the Punjab, the Inundation canals of the riverain tract were the most important then in working order.

The oldest of the works is the Western Jumna Canal built by Feroze Shah in the 14th century to convey water to the Emperor's hunting lodge at Hissar.

In 1568, the canal was renovated by Akbar, but it fell into disuse in the early part of the 18th century and was only reopened under the British Administration.

The alignments were along drainages instead of on the ridges of the country; swamps were formed and before irrigation developed to the present day science, all the defects and difficulties had to be discovered by experience.

In 1873, the remodelling of the canal, as a whole, was undertaken and the Western Jumna Canal is at the present day a modern irrigation work.

THE HASLI CANAL.

The Hasli Canal was constructed about the year 1633, by Ali Mardan Shah the engineer of the Emperor Shah Jahan. It was a small canal from the Ravi to bring water to Lahore, and a branch was led towards Amritsar to supply water to the sacred tanks of the Sikhs.

The Upper Bari Doab Canal was one of the first schemes to engage the attention of the administration after the annexation of the Punjab in 1849; the construction of the canal being regarded as a matter of political necessity.

Lieutenant Dyas of the engineers was instructed to frame plans on the pattern of the Ganges canal, then under construction, and the canal consisting of the main line and the Lahore branch was opened in 1859. An alignment had to be adopted different from that of the Hasli canal, the original alignment being utilized for distributaries.

The canal was renovated in 1873, and has been subject to continuous improvement ever since.

Direct political purpose has also been the cause of the inception of the Lower Swat and Upper Swat canals in the North-West Frontier Province and there are still across the Indus tracts of the country which the administration responsible for peace on the Frontier would like to see irrigated for the settlement of the border tribesmen.

The experience gained with the earlier canals was so encouraging that a progressive policy of construction has been maintained in the Punjab since the seventies. A table is annexed showing the dates on which the canals of the Province were opened and other data relative to each of them.

It is interesting to note that the capital expenditure on all canals excluding the Triple Project amounted in the year 1921-22 to £ 8,000,000 that the canals of the Triple Project have cost another £ 8,000,000 and that the total capital expended up to the year 1922 is nearly £ 16,000,000.

As experience has been gained in the construction of the canals, the works in connection with them have been improved.

The policy of improvement is continuous.

Briefly it may be stated that the improvements have consisted in the raising of the weirs across the rivers, the substitution in regulators and sluices of counterbalanced gates for gates of old pattern and narrow span ; the improvement in the shape and slope of distributary channels and the improvement in the types of outlets for the cultivators water-courses.

Two tables have been compiled, one giving particulars of the canals of the Punjab in 1921-22 and the other showing the development of the canals between 1901-02 and 1921-22.

Statement showing statistics of Perennial Canals in the Punjab in the year 1901-02 and the year 1921-22.

Name of Canals.	Discharge of the river from which the canal derives its supply. Minimum ever recorded.	Discharge of the river from which the canal derives its supply. Minimum recorded during the year.	Average Rainfall in the year referred to.	Minimum Discharge of Canal. As designed at first.	Minimum Discharge of Canal. Authorized in year referred to.	Minimum Discharge of Canal. During the year.	Gross area commanded.	Culturable area commanded.	Area Irrigable. By complete project.	Area Irrigable. In the year referred to.	Area irrigated in the year referred to.
1	2	3	4	5	6	7	8	9	10	11	12
Western Jumna ..	1,350	2,461 **2,894**	15·6 **17·85**	6,178	6,380 **6,430**	5,410 **6,131**	2,516,698 **2,707,286**	2,080,108 **2,024,407**	797,010 **893,555**	797,018 **893,555**	589,955 **855,363**
Bari Doab ..	1,272	1,334 **2,000**	32·8 **24·10**	5,000	6,500 **6,700**	6,231 **6,807**	1,641,660 **1,639,493**	1,479,257 **1,504,059**	8,87,500 **1,083,760**	849,074 **1,083,760**	856,041 **1,343,471**
Lower Bari Doab	..	..	**9·18**	OPENED IN 1913 **6,750**	**7,000**	**7,021**	**1,702,703**	**1,427,246**	**877,908**	**912,854**	**993,478**
Sirhind Canal ..	2,780	3,343 **4,085**	16·22 **17·46**	6,000	8,000 **8,541**	8,056 **9,009**	4,558,602 **4,363,864**	4,085,410 **3,667,221**	1,170,000 **1,204,323**	1,170,000 **1,170,000**	1,070,461 **1,924,494**
Lower Chenab ..	..	.. ..	11·49 **13·03**	8,313	10,730 **10,853**	10,717 **10,557**	3,160,830 **3,390,194**	2,905,635 **2,585,458**	1,608,808 **1,500,000**	1,499,470 **1,730,066**	1,748,129 **2,560,932**
Lower Jhelum ..	..	4,772 ..	.. **12·41**	3,800	3,800 **4,200**	835 **4,323**	1,139,500 **1,342,374**	968,577 **1,251,900**	611,972 **660,000**	120,137 **828,000**	.. **872,215**
Upper Chenab ..	**3,884**	**5,253**	**22·31**	OPENED IN 1912 **11,742**	**11,929**	**12,635**	**1,590,100**	**1,510,672**	**648,367**	**634,657**	**655,421**
Upper Jhelum ..	**4,000**	**7,294**	**12·71**	OPENED IN 1915 **8,380**	**8,380**	**8,724**	**603,740**	**573,329**	**319,557**	**319,557**	**358,567**

Figures antique refer to the year 1921-22.
Figures ordinary refer to the year 1901-02.

Principal interesting Particulars of Punjab Canals.

Name of Canal.	Date of opening.	Capacity as first designed.	Present aximum apacity.	Present area commanded.	Area irrigated during the year 1921-22.	Length in miles of distributary Channels.
Western Jamna	1873	6,178	6,430	2,324,407	855,368	1,889
Upper Bari Doab	1859 & 1873	5,000	6,700	1,504,059	1,343,471	1,569
Sirhind	1882 & 1884	6,000	8,541	3,667,221	1,233,619	3,424
Sidhnai	1886	1,820	1,820	278,088	209,409	251
Lower Chenab	1887—1893	8,313	10,853	2,585,458	2,560,932	2,243
Lower Jhelum	1901	3,800	4,200	1,251,900	872,215	1,046
Upper Chenab	1912	11,742	4,871 11,929	1,510,672	655,421	1,252
Lower Bari Doab	1913	6,750	7,030	1,427,246	993,478	1,202
Upper Jhelum	1915	8,380	2,000 8,380	573,329	358,567	666

The Upper Jhelum Canal and the Upper Chenab Canals are principally feeder canals transferring the Jhelum water to the Chenab and the Chenab water across the Ravi. The figure above the line in the column capacity indicates the water which is utilizable for irrigation on that system.

The Lower Chenab was opened as an inundation canal in 1887 and as a perennial canal in 1893.

The Sirhind Canal was opened for irrigation in 1882 but was not completed till 1884.

The development of irrigation in the Punjab has taken place within the last fifty years.

The initiative for the construction of each scheme has come from the government of the time and from the engineering staff employed by it.

The government has been of the nature of a beneficient autocracy, anxious for the welfare of the community and for its development.

It is possible to imagine that there must be a vast difference between a scheme inaugurated by a government, so placed and intentioned, and one developing with the gradual expansion of an agricultural community or one constructed by a concessionaire company anxious for dividends.

It is impossible to imagine the colony canals constructed and colonized by an agency other than that by which they were constructed. Undertaken as they were, these schemes could be framed as complete entities.

Many details are greatly simplified when undertaken by the state. For example:

The collection of the required information or statistics with reference to areas, cultivation, the likely water-rate, the acquisition of land, etc., etc.

For the financing of the scheme, capital can be acquired at the minimum rate.

As well, therefore and as economically as state enterprise can construct, these schemes were devised and constructed.

The development of the canals after construction have proved not quite as easy.

There has not been within this first half of the century that co-operation between the supplies of the water and the receiving client which one might ideally expect.

The supplier of water has been interested in increasing the efficiency of the irrigating machine, whereas the client, extremely conservative, has only been anxious to obtain as much water as will save him from the exercise of any effort.

It might even be said that any single village finds it difficult to conceive that the water can be meant for any other village except itself.

Increase in efficiency, however, there has been, and the cultivators have responded, with some fortitude, some resignation and many complaints to the efforts made to reduce waste. These efforts have, be it understood, resulted in decrease of supply, and necessity for more care in the application of the water.

Further efficiency can only be attained by making scarcer and scarcer, within limits of course, the valuable water.

So far, however, the cultivators have shown confidence in the attitude of the officers who have served them and the general results have been creditable to both parties.

Fifty years is not a lengthy period when the development of the agricultural method is considered.

There has been much improvement in the last 50 years and the future will probably see further improvement still.

CHAPTER II.

Rainfall.

THE STUDY OF RAINFALL.

While the development of irrigation in any country depends on the precariousness of the rainfall, the scientific application of irrigation necessitates accurate observation thereof.

PRECIPITATION OVER RIVER CATCHMENTS.

The rainfall as to be studied over the catchment area of the rivers from which the supplies are drawn, as well as over the area which it is proposed to irrigate.

Over the catchment area, the snowfall and the rainfall have to be associated with the discharges of the rivers throughout the year.

RAINFALL AND THE DISCHARGE FROM TORRENTS.

When a canal alignment crosses the beds of torrents in submontane tracts, adequate works have to be constructed to pass the discharge of the torrents across the canal.

There is an arithmetical relation between the catchment area of a torrent up to the canal alignment, the rainfall and the discharge of the torrent.

This relation has to be ascertained by observation. In such cases the **maximum intensity** of **rainfall** and the **duration of the rain storm** have to be studied. They are important factors influencing the discharge.

In the Punjab, the Upper Jhelum Canal, and in the North-West Frontier Province, the Upper Swat river canal are so aligned that they are crossed by numerous torrents. The construction of the cross drainage works created a fresh interest in the relation between rainfall and run off as a practical application of this relation was repeatedly called for in the design of these works. Cross drainage works both large and small have been constructed on all the older canals and on the more recent ones, but they were not as numerous as on the two canals above cited.

DEVELOPMENTS.

The first canals were constructed to utilize the abundance of water in the streams and rivers. Later when a greater demand for irrigation arose, when a more efficient utilization of the resources of the country in the matter of its water had to be considered, the study of these subjects became important. It may be necessary to decide whether another canal can be taken from a certain river which is already tapped. It is then important to know to what extent the rainfall can be relied on to eke out

the supply of water which the crops will obtain from irrigation canals, and also to know what can be expected as river supply. It is under these circumstances that the knowledge of the rainfall over long periods of years and the corresponding river discharges becomes useful.

As a rule irrigation is not required in those countries where the rainfall is sufficient and well distributed.

Insufficient rainfall or unevenly distributed rainfall is a feature of certain tropical areas.

Irrigation is practised in Spain, Italy, Egypt, India, Mesopotamia, parts of America, parts of Australia, and South Africa.

Table showing annual rainfall and fluctuation of rainfall (Mean annual fall taken as unity).

Name of countries.	Relative fall of wettest and driest years.		Average fall of two wettest and two driest consecutive years.		Average fall of 3 wettest and 3 driest consecutive years.	
	Wettest.	Driest.	Wettest.	Driest.	Wettest.	Driest.
British Isles ..	1·45	·66	1·30	·73	1·23	·78
Norway, Denmark, Holland, Belgium ..	1·48	·61	1·33	·66	1·26	·75
France ..	1·61	·59	1·42	·68	1·31	·74
Italy ..	1·59	·55	1·39	·70	1·29	·76
Switzerland ..	1·47	·55	1·35	·62	1·30	·68
Germany ..	1·39	·61	1·27	·70	1·21	·77
Austria ..	1·44	·56	1·33	·68	1·27	·76
Russia ..	1·66	·53	1·46	·63	1·35	·68
India ..	1·62	·52	1·42	·66	1·30	·72
Africa ..	1·66	·53	1·51	·64	1·42	·68
Australia ..	1·56	·53	1·39	·71	1·32	·75
United States and Canada ..	1·41	·68	1·31	·75	1·25	·79
South America and West Indies .	1·51	·55	1·45	·63	1·35	·69
Averages ..	1·51	·60	1·35	·69	1·27	·75

In the greater part of the Punjab where irrigation is required, the annual rainfall is 12 inches and most of the rain falls in July, August and the first half of September.

The average rainfall between the 1st of October and the 31st of March following is 2 inches. The Punjab is well suited to the development of irrigation. A system of irrigation canals over country which has a precarious rainfall renders that country independent of the vagaries of the rainfall and has a high value as an insurance against famine which follows drought.

Even in localities where the rainfall is much greater than in the Punjab, if it is not well distributed or if it is liable to fail in certain years, the necessity arises of introducing irrigation as a protection against those dry seasons.

The island of Mauritius produces a valuable crop of sugar-cane and in order to protect the crop during periods of drought a system of small irrigation canals fed from storage reservoirs, has been constructed.

In the Punjab, the principal crop grown between October and April is wheat which requires in that latitude 20 inches of water for an average outturn. As the rainfall amounts to 2 inches over the same period, the canal systems have to supply 18 inches.

Wheat can be grown in the Punjab, in certain parts without irrigation, and in other parts with irrigation from wells.

The area grown entirely on rainfall would be very small and often liable to complete failure. Previous to the advent of the canals the failure of the rains was the cause of famine. Famine is costly both in measures of relief and in waste of life; so much so, that as a protective measure only, expenditure on certain canals is justifiable.

RAIN GAUGES.

The practice which commends itself universally is the adoption throughout the area over which the rainfall is measured, of one pattern of rain gauge placed in a standard position.

The gauge is placed, as near as can be, with the mouth flush with the level of the ground. It is protected by a fence placed distant enough to avoid interference with the most driving rain. It is estimated that placed as ideally as possible a rain gauge measures 3½ per cent. less than the actual rainfall.

The deficit increases with the position of the gauge above ground level, in a proportion approximate to the square root of the altitude. The mouth of the gauge must be of accurate area and shape.

The area of the receiving or the calibrating vessel bears a fixed known ratio to the area of the mouth of the rain gauge and is made of smaller area, so that the rainfall can be magnified and small rainfalls measured with great accuracy.

CHAPTER III.

Canals, Rivers—River Discharge.

PERENNIAL CANALS AND INUNDATION CANALS.

In the Punjab, there are two classes of canals, which derive their supplies from the rivers; the perennial canals and the inundation canals.

The perennial canals, as the name implies, are maintained in flow throughout the year.

In order to maintain a canal in flow throughout the year, the river from which the canal takes off has to be dammed by a weir or barrage, so that the supply in the river during the period of low water be raised high enough to feed the canal, and be diverted entirely into the canal, no water being allowed to leak through the dam. It will be understood therefore that the capacity of the canal is limited to a certain extent by the minimum river discharge.

INUNDATION CANALS.

The inundation canals are those which derive their supply from the river when it is in flood, or during the period of inundation, usually from the 15th of May to the 15th of September. During this period the river discharge is swollen by melting snow in the catchment area, or by rain in the hills and plains.

The bed level of an inundation canal at the offtake is higher than the low water level of the river. The supply entering the canal is variable and owing to some silt deposit during the working period, the canal ceases to flow when the river level drops lower than the silted bed.

The silt deposits are cleared during the Rabi when the river is low and the canal does not flow. The supply obtained by inundation canals is usually sufficient for the Kharif crop and it is generally possible to obtain a preliminary watering for the Rabi crop as well.

THE RIVERS.

The rivers of the Punjab, have many features in common, they rise in the Himalayas, flow through the alluvial plain and then converge to join the Indus.

The beds are wide and sandy; within the limits of the bed the channels have a variable course and islands of silt increase or decrease in size, are formed or disappear, according to the set of the current.

In the winter the river discharge is very small and is limited to one or two small streams.

The winter months are October to March.

In the summer the river discharge increases, ten-fold and twenty-fold and in a flood the discharge may be over a hundred times as much as the normal flow in the winter.

The summer period extends from April to the end of September.

THE DISCHARGES COMPARED.

The minimum and the flood discharges of the river are compared :—

	Minimum.	Maximum.	
Jhelum (Rasul)	4,000	600,000	
Chenab (Khanki) ..	4,000	600,000	
Ravi (Madhopur) ..	2,000	260,000	(estimated).
Sutlej (Rupar) ..	3,500	300,000	

CONTINUOUS OBSERVATIONS ON THE FLOW OF THE RIVERS.

When the construction of canals in a scientific manner was started in the Punjab, the discharges of the rivers were observed periodically during the year, and an approximate estimate could be obtained of the variation in discharge throughout the year.

When the extension of irrigation and the utilization of all the supply available in the rivers throughout the winter a more intimate knowledge of the rivers has become necessary and recently special officers have been deputed to make observations of the river discharges daily throughout the year.

Sites for the observation of discharges are fixed at the confluence of the rivers and at the weirs or barrage across the rivers at the existing canal offtakes.

Information is thereby obtained of the behaviour of the river along its course ; losses and gains from percolation into and out of the soil are detected.

In the Punjab, the combined capacity of the canals is not limited to the aggregate minimum flow off the rivers which feed the canals.

When, in the winter, the river discharge is at a minimum, climatic and agricultural conditions are such that fairly long intervals can be permitted between the waterings given to the crops ; it is found from experience that the capacity of the offtaking canals can be three times as great as the minimum river flow, the minimum flow being distributed in turn to the branches.

The minimum river discharges of the rivers are compared in the annexed table with the capacities of the canals :—

River.	Minimum Discharge.	Canal.	Capacity.
Jumna ..	2,000	W. J. C.	6,430
Sutlej ..	3,500	Sirhind	8,541
Ravi ..	2,000 (app.)	U. B. D. C.	5,770 (Rabi) 6,700 (Kharif)
		L. C. C.	10,730
		L. J. C.	4,200
Chenab ..	4,000 (app.)	U. J. C.	2,000/ 8,380 (*a*)
Jhelum ..	4,000 (app.)	U. C. C.	4,871/11,929 (*b*)
		L. B. D. C.	6,750
			28,551

(*a*) Feeding capacity when supplying Lower Chenab Canal.

(*b*) Includes 7,000 for Lower Bari Doab Canal.

NATURAL STORAGE.

A natural storage is available on these rivers in the circumstance that the winter snowfall accumulates and does not melt till early summer ; the rivers rise and their discharge is increased long before the summer rainfall. The effect of the snow melting

causes a high river level during the summer. The effect of the rainfall is to cause freshets and floods which depend for their height and duration on the intensity and duration of the rainfall.

ARTIFICIAL STORAGE RESERVOIRS.

In the Punjab, so far no large reservoirs have been constructed for the purpose of conserving the abundant summer water for use in the winter. The possibility of resort to storage has been considered.

In other parts of India, in Europe and in countries where the favourable rivers of the Punjab have no counterpart ; storage reservoirs are necessary adjuncts to Irrigation schemes. These reservoirs or tanks as they are known in certain parts of India are either constructed by an embankment of moderate height across a wide valley or a masonry dam of great height across a narrow and deep gorge.

The dam at Assouan in Egypt is both long and of a fair height.

THE NAMAL DAM AND CANAL.

In the Mianwali district of the Punjab, a small canal, the Namal canal, is fed from water stored by the Namal Dam.

The capacity of the canal is 60 cusecs.

CHAPTER IV.

Flow off Catchment Areas—Cross Drainage Works.

FLOW OFF CATCHMENT AREAS.

In the Punjab, for the purpose of the construction of canals, the interest in the flow off catchment areas has been concentrated on the maximum run off which may be obtained from torrents at the points at which the torrents are crossed by the canal alignment.

Torrents may be described as streams tributary to one of the rivers (generally the one from which the canal itself takes off), which only discharge after rainfall.

They vary in size from small ones discharging less than 50 cusecs to large ones discharging up to 133,000.

The branches of the Upper Swat river canal which skirt the Maira plateau cross a large number of small torrents.

It is sometimes possible to divert a small torrent into an adjoining one by means of a cut and to provide only one syphon or culvert under the canal.

On the Upper Jhelum Canal, level crossings have been constructed to deal with the torrents crossing the canal at Jatli and Rahmanpur and to deal with the Jhaba torrent at Jaggu. On the Sirhind Canal the Budki and Siswan torrents cross the canal by superpassages.

Whatever form the crossings may take, they are expensive works to construct.

Should the waterway provided at the crossing be insufficient the work may fail and cause disaster. A factor of safety is therefore necessary. On the other hand it must not be so liberal as to cause an unreasonable capital expenditure.

There are fortunately no records of serious failure, nor has it appeared that any of the works constructed have been unnecessarily large.

On the contrary we generally find that the floods passed are in excess of the designed discharges.

For the correct calculation of the waterway to be provided, the maximum discharge which may be expected to reach the crossing has to be known. The catchment area of the torrent has to be surveyed in order to determine the area up to the limits of the watershed and to know the character of the ground.

RAINFALL INTENSITY.

The intensity of the rainfall has to be determined or closely estimated, especially the rainfall which takes place after several rainy days when the ground is already well soaked and the run off is rapid.

Generally for such reaches of a canal crossed by torrents, the officers in administrative charge decide upon a figure of flow off per square mile of catchment from considerations of the known rainfall intensity and the other factors involved. The computed discharge at each crossing is checked from cross sections of the torrent stream, determined from high water-marks, and from the slope of the torrent bed. A discharge of the torrent in flow is also measured where practicable.

With sufficient care in the observations, it is possible to obtain the requisite amount of accuracy.

Text books give empirical formulæ for the determination of the maximum flow off a catchment. The formulæ are complicated and are generally only useful for the restricted area whence they were derived.

In practice, a figure for the run off per square mile, checked as indicated, has to be adopted.

From experience in the Punjab, it is found that an intensity of 1″ per hour may at times be expected during several consecutive hours, especially in the rain tracts near the foot hills.

An unabsorbed rainfall of 1″ per hour is equivalent to a flow off of 640 cusecs per square mile and from the nature of the catchment it is necessary to determine what proportion of the 640 cusecs is likely to be absorbed and what proportion passed off after the 2nd or 3rd hour of rainfall.

If the intensity of rainfall is greater than 1″ per hour the flow off is proportionately increased.

When the catchments are steep and arid and the soil hard or rocky, the flow off from higher parts of the catchment may overtake the flow off from lower parts before the cross drainage work is reached.

The net result shows a proportion of unabsorbed rainfall which is greater than unity.

THE NATURAL DRAINAGES.

So far reference has been made to the flow off catchment areas, the discharges from which are conveyed in torrents across the canal alignment. There are also to be mentioned streams of a less impetuous character, some of which can discharge quite large amounts. These are the natural drainages of the

country a few of which might be crossed by the main lines of the canals.

It is rare for the main irrigating branches to cross drainages as their alignments lie along the ridges.

The flow off such a drainage would depend largely on the character of the area drained, with respect to cultivation. If the area is highly cultivated the run off per acre would be small, as the fields would be ploughed and would have small raised boundaries which retain the precipitation.

CROSS DRAINAGE WORKS.

Under this termination are included the masonry works which are constructed on a canal to deal with the flow of water across the canal. The flow is due chiefly to rainfall. The designs adopted are various and may be classified as follows :—

Inlets, Culverts, Syphons, Level Crossings and Superpassages.

When the discharge approaching the canal is not large and water levels permit, the water is allowed to flow into the canal through an inlet ; the inlet is so designed as to allow the inflow to enter at the full supply level of the canal. There are however certain inlets which have been constructed to discharge at a level lower than the full supply level of the canal and in such cases the canal supply can be closed off to prevent the water from the canal filling the lower reach of the drainage.

The rain water draining off the high spoil banks of a canal is also disposed of by being passed into the canal through inlets. These are of relatively small dimensions but have to be placed at frequent intervals as the drains leading to the inlets can be excavated to a small section only. These drains are also liable to get choked from various causes and the overflow from them is destructive to the bank.

SYPHONS FOR CROSS DRAINAGES.

The more frequent type of Cross Drainage work is the syphon, and this is so by reason of the relative levels at which flow the discharge in the canal and the discharge through the torrent or natural drainage.

They have been generally designed to pass the maximum flow with a velocity of 10 feet per second when flowing full. The barrel is usually made with vertical abutments, an arched roof and inverted arch floor.

They are usually built of brick masonry.

REINFORCED CONCRETE SYPHONS ON THE UPPER CHENAB CANAL.

In the first 24 miles of the Main Line of the Upper Chenab Canal. 12 drainage crossings have been constructed.

One of these has a masonry barrel and the remainder were built of reinforced concrete.

It was found that the drainages were crossed at the lower end of torrents which spread over the country in shallow spills and owing to the depths of the canal in the locality masonry syphons would have gone down to great depths in order to secure the requisite resistance against the lifting power of the water.

Reinforced concrete tubes reduced very considerably the depth of foundations and were more economical.

SYPHONS ON THE UPPER JHELUM CANAL.

On the Upper Jhelum Canal 53 syphons were constructed. The number of barrels varied from 1 to 12. For uniformity the barrel of 12 foot span was adopted. Forty of these syphons have barrels of one or more spans of 12 feet. The heights of the abutments vary from 3·5 to 13·15.

The syphons were constructed with brick masonry abutments covered over with 90° arch segments and rested on 75° segmental inverts, for the better distribution of the foundation pressure. At the syphons the canal was of net section only, without berms.

OUTFALL CHANNELS FOR SYPHONS.

The waterway of the syphon was designed to pass the accepted discharge with velocities of 15 f/s and even 20 f/s if there was enough free board for the heading up required. At the exit of the syphon, the water would be issuing in a stream very different in cross section and velocity from that represented by the torrent cross section. It was necessary therefore to provide outfall channels to secure that the stream at issue from the culvert should not, by sudden expansion, precipitate silt and so choke the issue, but that the issuing stream of high velocity and comparative small section should gradually expand without shock and loss of energy to a section which could be passed on to the torrent bed.

STEEL SYPHONS ON SWAT CANAL.

On the Upper Swat River Canal, it was in several instances found to be cheaper to carry the canal in a steel syphon across

the wide torrent bed. These syphons were circular in section, between 6 feet and nine feet in diameter. They were constructed of rivetted plates half inch in thickness for the larger ones and were bound at intervals with hoops of angle iron.

Details of steel syphons.

	Description.		How stiffened	
Machai Branch of Upper Swat Canal.	2 tubes 9·0 diameter.	Steel plate $\frac{1}{2}''$ thick with 4″ laps.	Double angle iron ring 3″× 3″× 3/8.	11′ ·8 centre to centre.
Abazai Branch of Upper Swat Canal.	1 tube 6·5 diameter.	Steel plate $\frac{1}{4}''$ thick 4″ laps.	Angle iron ring $1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{4}$.	8′ ·0 centre to centre.

LEVEL CROSSINGS.

Of level crossings to pass torrents across a canal, there are three built on the Upper Jhelum Canal, within a few miles of each other. These consist of an inlet or arched bridge admitting the water of the canal; then a row of sluice gates between piers in the area common to the canal and torrent and lastly the canal regulator controlling the flow into the canal. The inlet and the regulator are parallel to each other or nearly so and both are at right angles to the line of sluice gates. The inlet is not provided with any gates, but the piers of the bridge has grooves for the insertion of the wooden beams.

The sluices are provided with gates 40 feet wide between piers 4′ 0″ thick. The gates are 8′ 3″ to 9′ 9″ high and are so designed that they can be rapidly lifted in the event of floods which approach with rapidity.

At Jaggu and Suketar No. II the counterbalanced gates are in sets of four. Each set is operated from one central gear through a countershaft. By having the clutches in mesh four gates can be lifted simultaneously.

The function of the inlet is merely to close off the upper reach of the canal from the floods should this be necessary. The regulator admits into the lower reaches of the canal the volume of water required.

Another level crossing of importance in the Punjab is the one whereby the Upper Chenab Canal is taken across the river Ravi at Balloki. It consists of 33 spans of 40 feet each.

SUPERPASSAGES.

The Siswan and the Budki torrents are passed across the Sirhind Canal by means of two superpassages, the level of the bed of the torrent being at the crossing considerably above the full supply level of the canal.

The following table gives certain particulars of Cross Drainage Works which are of general interest :—

Name of Cross Drainage Work.	Drains.	Catchment area.	Designed to pass.	Representing an unabsorbed rainfall.	Maximum discharge sustained.	Remarks.
		Sq. M.				
Budki superpassage (Sirhind Canal).	Siwalik hills.	86	30,000	350 cusecs/sq. mile.	45,000	Capacity increased by raising parapets.
Siswan superpassage (Sirhind Canal).	Siwalik hills.	69	20,000	290 cusecs/sq. mile.	30,000 to 35,000	
Syphons on Upper Jhelum Canal.	Pabbis.	Various.	..	1,000 to 2,000 cusecs/sq. mile.	..	
Level Crossings—						
Suketar No. 1 ..	Pabbis.	175	175×550	550 cusecs/sq. mile.	..	
Jhaba ..	Pabbis.	61	61×1020	1,020 cusecs/sq. mile.	..	
Syphons and inlets, Lower Jhelum Canal.	Cultivated land.	Various small catchments.	..	10 to 30 cusecs/sq. mile.	..	

CHAPTER V.

Survey, Intensity of Irrigation, Duty of water, Capacity of Canals.

When the need arises to investigate a project for a scheme of irrigation, it is primarily necessary to survey the tract of country it is proposed to irrigate. In the Punjab, this tract is usually a Doab, *i. e.*, the watershed between two rivers or as in the case of Inundation canals, the riverain tract.

When the canals were taken along the drainage lines, it can be imagined that no surveys were necessary. The surveys for the earlier projects consisted of levelling along proposed alignments subsequent to a reconnaïssance, and after that check levelling.

SURVEYS ON THE LOWER JHELUM.

For the project of the Lower Jhelum Canal, it is recorded that a base line was laid through the Doab, the reduced level of the starting bench mark being obtained from the records of the Trigonometrical Survey of India. Parallel cross lines at right angles to the base line, at intervals of two miles, divided the country into rectangles. From the levels taken on the cross lines it was possible to plot a contoured map of the Doab and from the contoured map could be determined the alignment of the canal, its branches and distributaries.

Later, for colonization purposes, the country was divided up into squares of 1,100 feet side and from the closer contours obtained after levelling watercourses were aligned with accuracy.

SOIL SURVEY AND SURVEY OF WATER TABLE.

More detailed surveys are now ordered for a canal project and besides the level survey, a survey of the subsoil water table and a soil survey of the tract are also made. The detailed information is collected by the staff employed on the levelling work.

In undertaking a level survey, it will be first necessary to have a general idea of the country, either from a reconnaissance or from maps.

A base line would be laid down and from a known bench mark, by accurate levelling work a bench mark will be fixed on the base line, and the base line chained and levelled with great accuracy.

25 ACRE RECTANGLES.

For facility in recording irrigation, the country is now divided up into rectangles of 25 acres measuring 1,100 feet by 990 feet.

At every 1,100 along the base line a stone pillar is inserted to serve as a bench mark and distance mark. From this mark, cross lines will be aligned and levelled, the pegs being fixed at every 990 foot interval ; in this manner the country is covered over with rectangles, the levels of which are known. From these levels the plotting of a contour plan presents no difficulty.

When the survey of the tract has been completed, the details required for the preparation of the whole project will have been settled. These could be—

(*a*) whether the irrigation is to be perennial or only in the Kharif or partly perennial and partly Kharif,

(*b*) the intensity of irrigation,

(*c*) the probable duty of the water taking into consideration the crops to be produced.

From these data, the capacity of the distributaries, the branches and finally of the main canal is arrived at.

THE INTENSITY OF IRRIGATION.

Very early in the history of irrigation in the Punjab, the designers proposed to irrigate during the year every acre commanded, that is, they proposed an intensity of irrigation of 100 per cent.

But the earliest canals were troubled with waterlogging and later the general opinion favoured a limitation of the intensity of irrigation to 100/3 per cent. that is a supply was proposed sufficient to irrigate in a year one-third of the area.

The Sirhind Canal was designed to irrigate yearly 40 per cent. of the area commanded.

It was observed that where conditions were favourable and water available the cultivators irrigated as much as possible and when the Lower Jhelum Canal was designed, the intensity proposed was 50 per cent. and it was hoped that even if the cultivators spread this allowance of water as much as they could manage to, waterlogging would be avoided.

The estimated duty of the water was taken as 170 acres per cusec per year that is 50 acres in the Kharif and 120 acres in the Rabi, as was then obtaining on the Bari Doab Canal.

The working of the canals with their capacity fixed on the basis of these assumptions has shown that a very moderate estimate was made of the duty of water in the Punjab.

On the Lower Chenab and Lower Jhelum canals, the proposed intensity of irrigation is now generally 75 per cent. of the culturable commanded area and the duty of water measured at the outlet is taken on the Lower Jhelum Canal as 88 acres/cusec for the Kharif and 264 acres per cusec for the whole year.

The intensity of 75 per cent. is not uniform throughout these canals. At one time the Lower Jhelum Canal was divided into zones the proposed intensity in each of which was 40 per cent., 50 per cent. and 75 per cent., the zones were defined according to the depth of subsoil water within the limits of each zone. On the Lower Chenab Canal, the intensity of irrigation for the Kharif distributaries is 40 per cent. and for the tract of country around Hafizabad which is liable to waterlogging, the intensity has within the last ten years been reduced from 75 per cent. to 50 per cent.

As a result of the adoption of intensities of 75 per cent. with the figures assumed for the duty of water, and considering also that many fields can carry two crops in a year, there have been large areas on the Lower Chenab Canal where the yearly intensity of irrigation has risen to over 100 per cent.

The result of this high intensity is a rapid increase of the value of the land, the accretion of considerable wealth to the landowners, tenants and sub-tenants in the tract.

Corresponding to this there is a tendency to scarcity of tenants in those parts of the Punjab where in the absence of the facilities afforded by irrigation more fields have to be cultivated and more work done to obtain an outturn of produce sufficient for a living.

THE DUTY OF WATER.

The moderate estimate made of the duty of water can well be illustrated by a tabular comparison of the duties obtained.—

	1901-02.				1921-22.			
	Duty in acres per cusec of average discharge.		Δ i. e., depth (in feet) of water used on area irrigated.		Duty in acres per cusec of average discharge.		Δ i. e., depth (in feet) of water used on area irrigated.	
	Kharif	Rabi.	Kharif	Rabi.	Kharif	Rabi.	Kharif	Rabi.
Western Jumna ..	64	115	3·8	2·3	145	193	2·52	1·89
Bari Doab Canal ..	86	221	3·4	1·4	144	295	2·54	1·24
Sirhind Canal ..	55	177	3·9	1·6	162	251	2·26	1·45
Lower Chenab ..	83	180	3·83	1·65	123	261	2·98	1·40
Lower Jhelum ..	Not	fully	opened		121	217	3·0	1·68
Sidhnai Canal ..	114				164	..	..	..
L. B. D. Canal ..	Not	opened			101	152	3·6	2·4
U. C. Canal ..	Not	opened			94	226	3·89	1·64
U. J. Canal ..	Not	opened			97	195	3·77	1·87

The duty of water increases in proportion to the efficiency of a canal system ; it increases with the development of irrigation, with the better knowledge of the application of water which the farmer obtains by experience.

It is also thought to increase with the rise of the subsoil water level, but there are no figures to prove this, the delta or depth of water applied being those on land where the subsoil water level is close to the surface as where it is more distant.

During the first years after the opening of a new canal, the duty is low as the fields are more difficult to cultivate if they are in virgin soil, and the watercourses and outlets are not at maximum efficiency.

CANAL EFFICIENCY.

The efficiency of the canals has been considerably increased by the correct apportioning of outlets and by causing the rotational closures to be effected on whole distributaries or branches

rather than on the outlets of a distributary ; also by improved maintenance.

Experiments have been made to determine the suitable depths and number of waterings for the wheat crop, the result of these experiments have enabled measures to be taken to check waste and carelessness.

The farmers themselves have acquired experience in the use of the water and with the ambition to extend their sowings have decreased the depth of watering generally with advantage to their holdings and the outturn of their fields. They have appreciated in certain localities that good cultivation of the soil can make up for lavish application of water to the advantage of the outturn.

THE CAPACITY OF A CANAL.

By the capacity of a canal is understood the maximum volume of water which the canal can safely carry, and generally, this will be the same as the discharge for which it was excavated and graded.

It has been found possible to increase the capacity of canals by a certain amount by widening them or strengthening their banks or by passing down the canal a depth of water greater than was at first intended. The masonry works across the canal have been, for the amount by which the capacity was increased, of sufficient waterway.

The following instances are quoted in illustration :—

(*a*) the capacity of the Lower Jhelum Canal was increased from 3,800 to 4,200,

(*b*) the capacity of the Lower Chenab Canal was increased from 8,313 to 10,853,

(*c*) the capacity of the Sirhind Canal was increased from 6,000 to 8,500.

INUNDATION CANALS.

When canals are excavated as were the Inundation Canals, by individual administrators, or under some communal system, they were not excavated to a capacity determined by survey

and by the application of factors for intensity and for the duty of water. The limits of irrigation of the canals and the duty were discovered afterwards.

When these canals came under scientific control, the theoretical considerations became applicable to the extensions and to the work of re-excavation or reconstruction of the silted head reaches which has to be undertaken yearly.

Although as has been shown, the capacity of a perennial canal can be increased to some extent without very great difficulty, yet in a scheme for the construction of such a canal the capacity of the canal has to be determined with accuracy, for on this capacity depends all the work to be done and the cost of the scheme. A difference of a foot in the bed width or in the depth of the supply will generally mean a large difference in the cost of any canal.

CHAPTER VI.

Alignments.

The Doabs or watersheds between the rivers of the Punjab have many features in common and there is a general resemblance between one network of canals and another.

Provided with a map of the Doab on which the contours have been marked, the alignment of the main canal does not represent a difficult undertaking. As in all engineering problems, this will be one requiring the consideration of the factors involved but, all things considered, it will be a problem of fairly easy solution.

The main canal and the branches will lie on the most prominent ridges of the country and the long straight reaches of most of the canals testify to the case with which the alignment is fixed.

The exceptions have been, in the Punjab, the Upper Jhelum Canal in the reach between Mangla and Rasul, and in the North-West Frontier, the alignments of the branches of the Upper Swat Canal.

In the Upper Bari Doab, the main canal occupies nearly the centre of the Doab, a position similar to that of the northern branch of the Lower Jhelum Canal in the Jechna Doab.

In the Doab irrigated by the Lower Chenab Canal, the Rakh and Mian Ali Branches cover the centre of the Doab, while the Jhang and Gugera Branches irrigate the land on each side of the central plateau.

The Sirhind and the Western Jumna Canals which cover the country between the tributaries of the Indus and those of the Ganges do not resemble the others as closely.

LOCATION OF HEADWORKS.

Connected with the alignments of the main canals is the problem of the determination of a site for the headworks, that is, for the offtake from the river. In the case of the Sirhind Canal,

the Lower Jhelum and the Upper Chenab, in each of which cases, the canal offtakes from the river as it emerges from the last range of hills, there are salient features of the country which indicate these localities as the desirable sites for the headworks of the respective canals.

In the case of the Lower Chenab Canal, it may be taken that having determined what water levels were required at Sagar, the highest point of the Doab, a point in the river was chosen so that the water level there would, allowing for the slope of the main canal, give the required level at Sagar. At Sagar the various ramifications of the canal converge into the main canals.

In the early days of canal construction in the Punjab there did not appear to be, among the Engineers, any keenness about weirs which would obstruct the water level and raise the water to the level required ; they were disposed to go further upstream and to find there the water level required.

The Mangla headworks and the head reach of the Upper Jhelum Canal have presented a special problem. The location of the alignment of the canal in the Gujrat District beyond the Pabbis was easily determined, and to bring the water there, there was the alternative of crossing the Pabbis or coming round *via* Rasul. The former alternative was ruled out owing to the depth of cutting (300 feet). A crossing of the river Jhelum by the canal was also ruled out owing to the cost of the work, so there remained the alternative of an alignment skirting the Pabbis.

Finally of two alternative sites for the Head Regulator that at Mangla was adopted as it was estimated to be the less costly of the two.

CHAPTER VII.

River Training.

The rivers of the Punjab have since many centuries wandered over very wide beds secured through the alluvial deposits through which the courses of these rivers lie.

Abandoned river beds indicate how rivers may change their course.

River Training consists usually in the construction of stone protected (stone pitched) embankments which will confine the current of the river to the direction required through the bridge or over the weir, in order that these works be saved from the onslaught of the current in an unexpected direction and the consequent effect of undermining scour.

THE RAILWAY BRIDGES.

In comparison with the river training works undertaken by the Engineers who build the railway bridges, the work of that nature undertaken by the Engineers of the Irrigation Branch in the Punjab is of lesser account, but is nevertheless of much interest.

PERMANENT CHANNEL AT HEADWORKS.

When a weir is aligned across a river and a canal is aligned for some miles at a short distance from the river, it becomes important to ensure that the course of the river approaching the weir and continguous to the canal be made permanent.

More so, when, as is often the case, the main stream of the river when it passes over or through the work is at a different place to that previously occupied by the unrestricted natural stream.

It is necessary to take such precautions as will preclude the possibility of an outflanking movement of the stream or a cutting into the alignment of the canal. Such a contingency might have disastrous consequences.

TRAINING THE APPROACHES.

In extension of the abutments of the weir and of the other works comprising the headworks of a canal, there are constructed stone pitched embankments which keep the river within the required precincts.

The width of the river between the high banks, that is, that part of the river known as the "Khadir" may be between two and four miles in extent.

The weirs at Khanki, Merala and Rasul are nearly a mile in width, and it is now appreciated that those built at Khanki and Rasul were built too wide.

The restriction of the river to the mile width was, at the time, considered to be quite a feat.

MODERN PRACTICE IN RIVER TRAINING. GUIDE BANKS.

By far the most important work on river training has been done by the Engineers responsible for bridging the wide rivers in the Punjab.

Very cautiously and at great expense has the modern practice been evolved.

Modern Practice may be described briefly as consisting of the construction of two parallel guide banks in extension of the abutments of the bridge and the adoption of a width between the abutments no greater than will be sufficient to pass the maximum possible flood, with the deepest scour that the bed is likely to assume.

The capacity of the river to scour is determined from soundings above and below the bridge.

The abutments and guide banks are constructed with sufficient provision to withstand the deepest scour.

The guide banks are constructed of sufficient length upstream to ensure that the approaches to the bridge will not be affected by any bend or embayment which the river may make in the area between the guide bank and the approach.

At the first applications of the guide bank principle, it was proposed to have the upstream guide banks as long as the bridge span, but practice showed that this was unnecessarily long and that a length of 1,100′ was all that was required. This length of 1,100 represents the likely depth of embayment of the stream some 500 or 600 feet plus a margin of equal length to permit of still-water conditions near the approach.

STILL-WATER BEHIND THE GUIDE BANK.

Still-water is essential in the area between the approaches and the upstream guide banks. In earlier practice the end of the guide bank is turned round to meet any current which may approach it from the rear and is armoured against such a contingency.

In later practice straight heads were adopted as they were found to be more satisfactory.

The down stream guide banks are usually about five chains in length.

THE APRONS.

As far as possible the aprons of all the guide banks are laid in the dry and are of such a width that assuming maximum scour to occur next to the guide bank, the apron on subsiding will pitch the slope right to the bottom of the deepest possible scour.

The apron should be, in width, 1·5 times the estimated maximum depth of scour measured from low water level.

The apron is usually laid just above low water level, *i. e.*, at the lowest level it is possible to work in the dry. The apron should be at least 4 feet in thickness. The stone laid on the slope of the guide bank is for the protection of the bank between low water level and high water level and that stone must on no account slip.

The necessity therefore of having a very adequate apron is all the more apparent.

RESERVE.

A reserve of stone is collected on all embankments ; and embankments for the protection of railway bridges carry service lines on which it is possible at short notice to take train loads of stone.

PIERS.

The piers of a bridge should be founded at such a depth that they will be unaffected by the greatest possible scour. It has been shown repeatedly that the cost of protecting comparatively shallow piers by throwing stone has been so costly as to have justified sinking the well foundations to enormous depths.

The stone thrown around the piers has, besides, the effect of restricting the waterway and diminishing the efficiency of the bridge.

THE OLD SPUR SYSTEM OF RIVER TRAINING.

Previous to the adoption of the guide bank system for training rivers the method in vogue was to have a retired embankment, set well away and therefore theoretically safe from the vagaries of the river and then by means of spurs and groynes

to give the errant river a kick here and a pat there wherever it showed signs of shooting crooked.

The material adopted for the spurs, *viz.*, trees, branches, grass, ropes, grass cables, mats, fascines of tamarisk were all of a perishable nature and even if stone were used for weighting down the perishable material it was insufficient to be of any lasting use.

There was no finality to the work and the expense was recurrent and increasing.

These objections drew the attention of Engineers to the necessity for something better and the guide bank scientifically designed and constructed was the outcome.

SERIES OF T-HEADED TRAINING SPURS.

As a variant of the guide bank system may be mentioned the method which has been adopted, with success as it is stated, of constructing two sets of parallel T-heads connected by embankments (shanks or spurs) to parallel retired flanks.

The method is only justifiable by reason of its lesser cost and for this justification the T-heads should be not less than ½ a mile apart.

The system is supposed to be effective by reason of the scours at each T-heads becoming confluent through their relative proximity and thus training the river centrally.

The stone protection of the T-head is similar to that adopted for the slope and apron of guide banks.

With the added improvement of designing the initial spurs on the same principle as the impregnable head of a guide bank, the variant deserves consideration.

Such a method was adopted between the Rajghat Railway Bridge on the Ganges and the headworks of the canal at Narora.

RIVER SURVEY.

Once a year at the site of each headworks the river is surveyed and a record is kept before the Engineers of the course of the river.

Besides soundings are taken of the protective aprons of all embankments.

RIVER DIVERSION.

At the construction of most of the headworks, it becomes necessary during the final stages to divert the main stream of the

river from its natural channel to that provided for it, for example from its natural channel towards the weir.

One of the flanking embankments when complete closes off the natural channel and the construction of the embankment through the final gap is an engineering feat of some importance.

The river is led away by leading cuts to such an extent as may be possible and the final breach is closed, a matter requiring experience and organization.

The method of diverting a river must depend on local conditions.

It is evidently preferable to close a broad shallow channel than a narrow and deep one.

The channel to be diverted is narrowed from both ends by embankments on a selected alignment: the embankment is pitched with stone, when the velocity of the stream through the narrowing gap is high enough to start erosion.

When a diversion is to be made, the river bed is protected over the requisite area with a mattress or thick layer of woven twigs, the tamarisk which grows in profusion on the river banks being most useful for this purpose.

Wire netting is useful to strengthen the mattress.

The mattress is either weighed down with stone in crates of wire netting or nailed down to the river bed with piles.

When diverting large streams, it is necessary to bridge over the final gap by intermediate piles or piers before the embankment can be completed.

A temporary roadway across these permits of rapid delivery of earth and stone.

Earth and stone can also be brought to the gap in boats if these are numerous enough.

AT INUNDATION CANAL INTAKES.

On inundation canals it is often necessary partially to divert a river stream by the erection of spurs of a temporary nature which are meant to direct the river stream to the canal intake when the river current tends to get away from it.

These works are from their nature, of a temporary character, but much may be achieved by ingenuity and correct practice.

PART II—WORKS.

CHAPTER I.

The Headworks of a Canal.

It is not intended here to investigate the theory of the design for the headworks of a canal or to examine in detail the construction of those which have been built. It will be understood that the design of the headworks of any canal is a work of magnitude and it is subject to much study.

The history of the design and execution of works of similar magnitude will be taken up and defects as well as any causes of subsequent failure would be investigated with the object of avoiding the same errors. A few general points can, however, be taken up.

The headworks of a canal consist generally of a weir across a river, undersluices, in extension of the weir, a regulator for admission of water to the canal, and rivetted embankments to maintain the river within the limits of the works.

The object of the weir is the retention of the river supply in order that it may be diverted into the regulator of the canal at those periods of the year when the river supply is comparatively small and it flows at a low level.

Also the weir should so head up the water that with the river at average summer level, the head of water obtainable at the undersluices. is sufficient to ensure a velocity in the channel passing through the undersluices, which will prevent the deposition of silt.

In the unchecked river, the difference between the water levels prevailing in the winter and the summer may amount to 15 feet.

EARLY DESIGNS.

The earlier designers proposed not to obstruct the stream when in flood and only to dam the winter supplies; and in order to effect this, constructed comparatively low masonry weirs, the crests of which were surmounted by hinged shutters

of steel plate which were raised and strutted, to dam the supply in the cold weather.

Although these weirs when closed by the erected shutters were of sufficient height to fulfil the purpose of stopping the supply in the low supply period it was found that at certain headworks notably at Rasul and Khanki the weirs were not of sufficient height, or alternately, were too wide, when the shutters had been dropped, to cause an effective obstruction of the stream in the flood season and a consequent high velocity past the regulator through the undersluices.

The velocity through the wide weir and undersluices was low and a deposit of sand in front of the canal resulted, and it was always feared that the sand might be carried into the canal and raise its bed so as to make it ineffective in drawing the required supply from the river.

By raising the weirs though 3·5 at Rasul Headworks and 3·85 feet at Khanki, the flood discharge now flows past the undersluices without leaving any troublesome deposit.

THE UNDERSLUICES.

The undersluices are a continuation of the weir and are situated between the weir and the regulator of the canal.

The weir is at a higher level than the bed of the canal, but the floor of the undersluices is at or near to canal bed level.

Water is admitted to the canal over a raised cill or crest.

The effect of the arrangement is to ensure a rapid stream of water past the canal regulator when the river is in flood, and even if occasionally, some mud is deposited over the floor of the undersluices, it is not drawn into the canal by the water entering.

When the water level is low as in the winter, and there is just sufficient water for the canal, the undersluices are closed and tamped. In the low water period the water is clean and there is no objection to ponding up clean water. Muddy water must, however, be kept moving.

Undersluices have generally been designed of generous waterway.

The first to be constructed in the Punjab were those of the Western Jumna Canal at Tajewala, and these were found to be of excessive waterway.

Next in turn were the undersluices constructed for the Upper Bari Doab Canal at Madhopur which consisted of twelve bays, twenty feet wide and since then the undersluices at Ropar, Khanki, Rasul and Marala have been copied on the Madhopur pattern.

It is noticed that even in the newly designed headworks at Sulemanke the waterway 240 feet has been retained, eight bays 30 feet wide being substituted for twelve 20 feet wide.

When canals take off from each bank of the river, undersluices are provided at each end of the weir in juxtaposition to the regulators on each bank of the river.

IMPROVEMENTS.

Improvements have consisted in the substitution for slow moving gates, of counterbalanced rapid moving ones. The advent of the counterbalanced gate has also made it possible to adopt wider spans and whereas twenty years ago twenty foot spans were wide enough, present practice adopts 30 foot spans and over.

At most headworks, sand or silt tends to collect in the area facing the regulator and the undersluices, and one object of the design of these works and the method of regulation of the stream is to avoid this accumulation.

With the improvements introduced this object is easily accomplished.

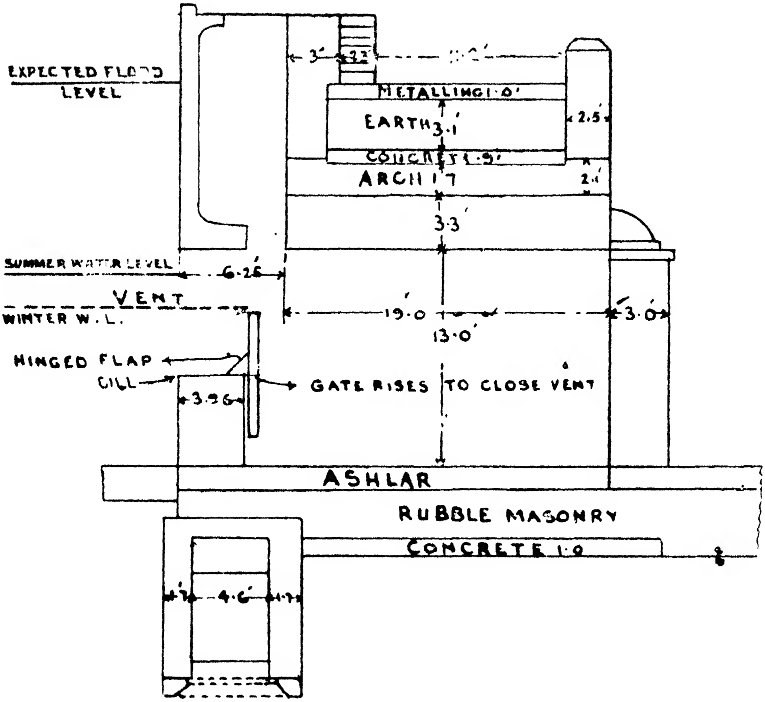
DIVIDE GROYNE.

Between the undersluices and the remainder of the weir there is constructed a stone rivetted embankment, or a masonry wall in order to divide the comparative slow stream over the weir from the swift stream which passes the undersluices. It is called the Divide Groyne and should extend to a point opposite the end of the canal regulator. There does not appear to be any object in extending it beyond, although at Rasul it is almost as long again.

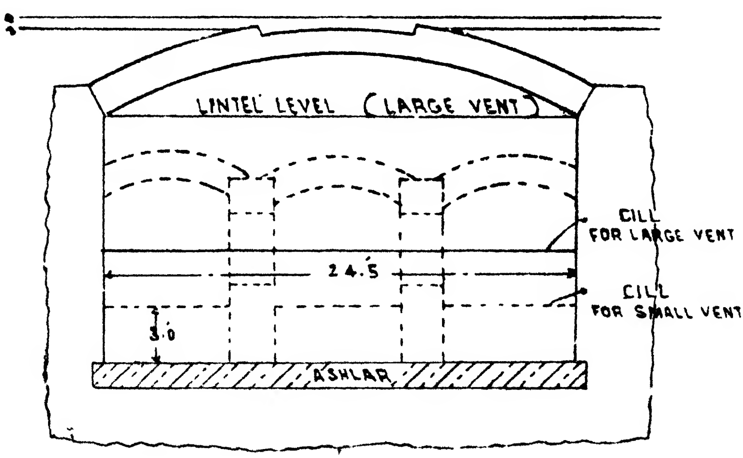
THE REGULATOR.

The improvements in the regulators admitting water to canals have consisted in taking the water over as high a cill wall as economical and convenient, and in increasing the span of the gates from six and a half feet which was common twenty-five

DIAGRAM OF IMPROVED REGULATOR FOR A CANAL.

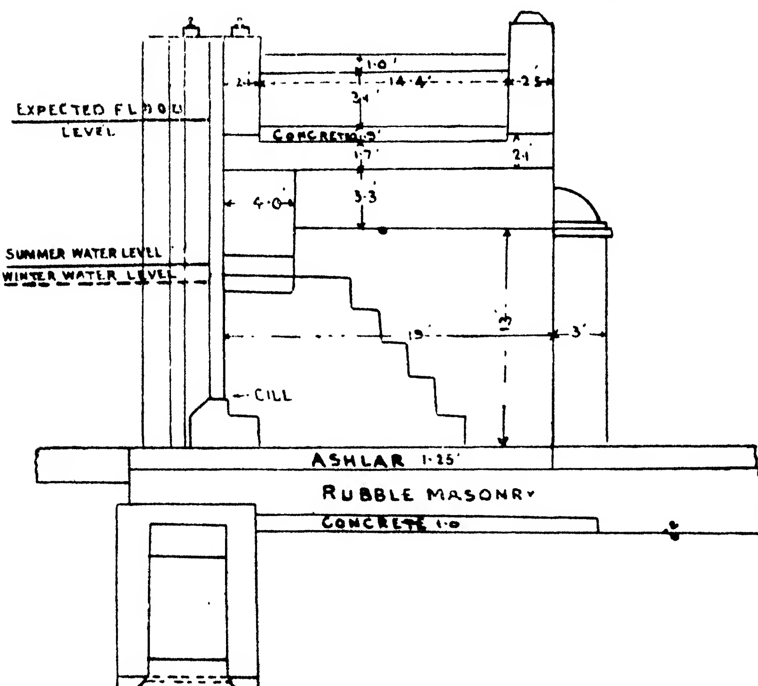


CROSS SECTION OF A REGULATOR
COMPARING
LARGE & SMALL VENTS
SMALL VENTS SHOWN DOTTED



View of a Canal Regulator and Sluices.

DIAGRAM OF A REGULATOR FOR A CANAL OLD ARRANGEMENT



years ago to twenty-five feet or thereabouts. The counter-balanced rising gate has also been substituted for the drop gate, supplemented by a moveable cill of *karris* which was the common practice.

The rising gate serves as a movable cill and can close the vent.

Under certain circumstances of river level and canal supply as at Rasul, the shutters on the weir can be dispensed with altogether and a safer and more easily controlled headworks is the result.

In appearance the headworks of a canal differ considerably from those of twenty years ago.

The steel superstructure from which are suspended the gates and the counterpoises is now a prominent feature. Formerly the gates were raised by travelling winches large or small which moved on rails across the tops of the piers. The piers projected beyond the gates and on the extension beyond the gate were the grooves in which the beams or *karris* were dropped on to the cill.

The river face of the regulators, at Khanki, Rasul and other places where the regulator has been altered now consists of a plain reinforced concrete panel or breast wall with horizontal lintel. The piers do not project beyond the face wall or the cill.

The interval between the cill and the lintel forms a vent which can be closed by the rising gates.

In designing the headworks, on the Sutlej river, for the Sutlej Valley Project, the modern system of river control by sluice gates throughout the width of the stream has been adopted.

This involves more accurate calculation of the waterway required and the training of the river towards the work by means of the guide bank system adopted for railway bridges over the large rivers.

The old weirs were broad and shallow and occasional scours threatened the foundations. The new headworks are narrow and deep and the foundations are all beyond the range of scour.

With regard to the arithmetical design of the parts of the masonry works, the following points are noted :—

The weight on the foundations of the piers and walls should be within safe limits considering the nature of the foundations ;

when building on sand, well foundations, generally ensure that no uneven settlement will take place.

In designing the piers of the regulator, it will be necessary to consider the structure as a dam when the canal is closed and the river in flood.

The floor of the weir has to be designed safe from piping, or flow beneath the work, safe from the upward pressure of water impounded above the weir and resistant to the fall of water on the *talus*.

All these points the Engineer is usually sufficiently well primed to deal with ; and he has besides the example of other works to guide him.

The parts of a headworks which have been generally on the weak side are those parts subject to the scouring effect of the stream. The noses of the groynes, especially of the Divide Groyne, the floor of the undersluices and the bed and slopes of the canal below the regulator.

The destruction of the unnecessary kinetic energy in the water as it passes some parts of the work is not yet sufficiently understood. No contrivances are made to absorb the surplus energy which works its destructiveness unchecked. as the water flows into the canal through the head regulator, or as it flows through the undersluices.

View of a Distributary.

CHAPTER II.

Channels in Earth.

Canals, Branches, Distributaries.

ALIGNMENTS.

The alignment of the main branches of a canal is fixed without much difficulty on the commanding ridges of the country and the capacity of any branch is determined by the area having as boundary the valleys on each side of the commanding ridge. The other boundaries would be the canal alignment and the limit of irrigation for the system. The main boundaries would, in general, be well marked ones.

The next step is to fix boundaries for the distributary channels and to determine their capacity. Ridges of the country, second in importance to those on which are aligned the main branches, are selected for the alignments, the boundaries on either side being the lowest points of the valleys on each side of the ridge selected.

In country to be colonised, the boundaries of villages are made to coincide with the alignment of the distributary. If the distributary is to be constructed through settled country, consideration cannot be given to the boundaries of villages, as the alignment of the distributary must be governed by the run of the high grounds.

DRAINAGES.

It is obviously bad practice for the irrigation from a distributary to cross the lowest point of a valley. For this purpose the watercourse would have to be embanked across the valley and the bank would interfere with the natural flow of surface drainage.

In the Punjab, generally, the lowest point of the valley between ridges are not clearly or sharply demarcated and in practice irrigation has sometimes been taken across the valleys.

The valleys would be the courses taken by any surface flow following on rainfall and some surface drainage would occasionally pass down. Cultivation tends to obliterate the drainage lines, but it is important that they be kept open in irrigated country.

If canal watercourses are permitted to cross the drainage lines the latter will not be able, at all, to perform their functions as surface drains.

CAPACITY PER UNIT LENGTH OF DISTRIBUTARY.

In fixing the alignments of distributaries, consideration is also to be given to the length of the distributary in proportion to its capacity ; on account of the losses by absorption into the ground the distributary must not be too long. Again outlets cannot be constructed with fine accuracy ; each individual outlet may draw more than its share and cumulative errors in this respect are a cause of distress. Practice has shown that short distributaries are more easily managed than long ones.

Distributaries are seldom more than 30 miles long.

The majority of distributaries appear to be between five and ten miles in length and the capacity is usually about 5 cusecs per mile.

Distributaries above 15 miles in length take about 6 cusecs per mile.

Distributaries between 20 and 30 miles long carry about 7 or 8 cusecs per mile.

Many distributaries exist which have a capacity less than the average figures given.

As efficiency of irrigation and distribution increases the cusecs per mile ratio tends to decrease.

The following official definitions have been adopted for channels graduated according to their capacity.

Main Canals, Branch Canals, Distributaries, Branch Distributaries, Minors.

THE FIRST DESIGN.

The earlier designers of canal systems sub-divided the channels into main canals, branch canals, major distributaries, minor distributaries, and the outlets would as much as possible be placed in the minor distributary. The object was to get the water as close to the land as possible before it was given over to the cultivator. The land adjacent to both major and minor distributary would be served by the latter.

If the minor distributary had exceptionally good command no trouble would be felt.

But exceptionally good command is rare. There would be loss of head through passage of the water from major distributary to minor distributary and again through the outlet.

This double loss would be obviated and command improved or secured when there was none before, if the outlets were placed in the major distributary. The cultivators appreciated this difference and struggled to get their outlets placed in the major distributary.

Minors originally designed of large capacity dwindled to a small capacity, as outlets were transferred from minor to major distributaries. When improvements in the methods of distribution were introduced, most of the minor distributaries became as such, obsolete ; the channels were retained as watercourses for the more distant villages, access to which was through the lands of other villages or across depressions which an ordinary watercourse was not considered capable of crossing.

The minor in fact was often constructed to carry the water through the lands of other villages or across difficult country before it was made over to the cultivator. Minor distributaries are necessary in certain localities, but in every case where the cultivators can obtain water from a major distributary it is now considered better practice that they should so obtain it.

COMMAND.

Practice in the Punjab brought to light the fact that in the earliest scheme, the distributaries were constructed with poor command. This defect has been remedied in the course of years by raising the banks and the controlling masonry works.

Command may be defined as the margin which exists between the water level in the distributary and the water level in the watercourse, when the watercourse is irrigating the highest fields served by it.

On a well designed system in the Punjab the water level in a watercourse need not fluctuate very much if the boundaries of the area served by the watercourse have been fixed with due regard to levels, as the country is nearly flat.

The watercourse requires a slope of two feet a mile.

But even small fluctuations in the water level of the watercourse which may amount to 0·5 feet are enough to cause variations in the discharge of the outlet sufficient to upset the distribution of water in the supply channel unless the outlet is so designed as to overcome the effect of these variations.

An outlet, as modern conditions require, needs a head of six inches to one foot according to the depth of the distributary.

A further condition governing the design of distributaries limits the length of watercourses to 2 miles.

From the foregoing it is possible accurately to indicate what the water level in a distributary at an outlet should be, taking into consideration the general slope of the country from the ridge on which the distributary is placed.

THE SECTION AND GRADIENT OF THE DISTRIBUTARY.

For canals in the Punjab, a channel which has the minimum area for the greatest discharge is of no use at all. Its depth is too great in proportion to its bed width.

The canals of the Punjab carry silt laden water and have to be designed to carry this water without any precipitation of the load.

There is another condition of an opposite nature; the soil in which the channels are excavated is sandy loam and that soil cannot withstand a higher mean velocity than 3½ feet per second (sometimes 3·75 f/s).

If higher velocities than this are obtained, the channels become distorted in shape, and this adds a considerable amount to the cost of maintenance.

CRITICAL VELOCITY.

By observation of the dimensions of a number of channels in stable condition of regime, it has been ascertained that a relation which can be expressed numerically as $V = 0{\cdot}84\, d^{0{\cdot}64}$ exists between the mean velocity and the depth. This velocity is commonly called critical, and the assumption is that a greater velocity will cause erosion and a lesser induce silt deposit.

The equation is, while being empirical, accurate enough for purposes of design in the Punjab and until more accurate co-efficients and exponents are obtained by a wider range of

accurate observations, the present equation will hold good. It is possible generally to work to about ten per cent. above or below the critical velocity without coming to grief, and also it is to be noted that the critical velocity is variable within a small range, depending on the matter in suspension.

RANGE OF VELOCITIES.

The practical range of mean velocities, is from 1 foot per second for small watercourses of about 2 cusecs capacity to 3·75 f/s for channels discharging 10,000; the range of velocity is therefore comparatively a restricted one.

RATIO BED WIDTH TO DEPTH.

In the first instance, it was thought that the ratio of bed width to depth was independent of the circumstances which induce stability of shape in a channel. It is known, however, from experience that channels which are too wide will become narrow by an increasing deposit of clay on the sides. These channels berm up. Similarly a channel will erode its sides as the Main Line of the Lower Chenab has done.

Later the following figures were given for the ratio of bed width to depth :—

Up to 10 cusecs	B/D= 3·5
25 ,,	4·0
100 ,,	4·5
200 ,,	5·0
500 ,,	6·0
1,000 ,,	7·0

There is a small range of choice of slopes to which a stable channel can be constructed, and Engineers have to use their experience in selecting the best one.

The one with the steepest gradient would evidently have the smallest section. If the Engineer were remodelling, he would select the section that would involve least work. For distributaries generally it will be found practicable to select a slope between 1/3,333 and 1 in 5,000 and for minor distributaries a slope between 1 in 2,000 and 1 in 3,333. The range of choice is comparatively small.

NARROW AND DEEP SECTION.

Previous to the investigation into the subject of non-silting sections, channels used to be excavated narrow and deep ; they silted themselves to a stable section and were periodically re-excavated in order to pass on supplies.

It is noticeable that the old designs were faulty when small discharge were dealt with, as in distributaries and specially minor distributaries ; the main canals which had to be designed to the limiting maximum velocity were generally accurately dimensioned.

CHANNEL EXCAVATION.

It is usual to excavate leaving slopes of one to one.

The excavated earth is used in forming the bank, when the channel is partly in excavation and partly in embankment, or is carried to a spoil bank if the channel is entirely in excavation.

When the channel is completely in cutting, the patrol bank is formed with its top 2 feet above natural surface for large canals and 1 foot above natural surface for distributaries.

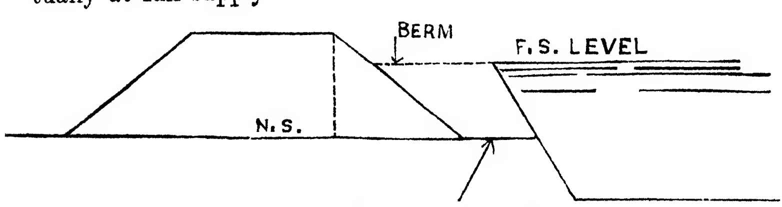
When the amount of earth removed from the excavated portion is sufficient to make up the banks, the channel is said to run in balancing depth.

A few simple rules have been gradually evolved and are now common practice. These will be noticed as the subject is dealt with.

Embankments are made with slopes of 1·5 to 1 as these are sufficiently stable.

A berm is usually left at natural surface level when making the filling for a channel partly in excavation and partly in embankment.

By deposit from the water the berm grows and is eventually at full supply level.



BERM LEFT AT NATURAL SURFACE

The top surface of banks is made 3 feet above full supply level in the case of main canals ; 2 feet above full supply level for branch canals and 1·5 for distributaries. The banks of small channels are made 1·0 above full supply level.

The banks of main canals and branches are made twenty feet wide and fifteen feet wide respectively to provide a road which will take vehicular traffic.

If no traffic is to be provided for, the minimum width of bank is ten feet.

The banks of distributaries are made 5 feet wide.

High embankments need to be specially designed and carefully constructed.

On the Upper Jhelum Canal numerous high embankments were constructed. They were usually twenty feet wide at the top with outer slopes of 1 : 4 and these slopes were turfed to avoid denudation by rain.

A very strong embankment can be made with a sand core covered with two feet of clay.

The clay in the formation of all banks should be finely broken. The finer, the better. If a bank is constructed entirely of clay, it is necessary to build layer by layer about 2 feet in thickness and to roll each layer.

BERMS.

Berms at full supply level are valuable as protection to embankments.

So constructed, the capacity of the channel suddenly increases at berm level and the channel can deal with excesses of supply without the danger of overflowing or of the breaching of the dry and porous clay bank above full supply level.

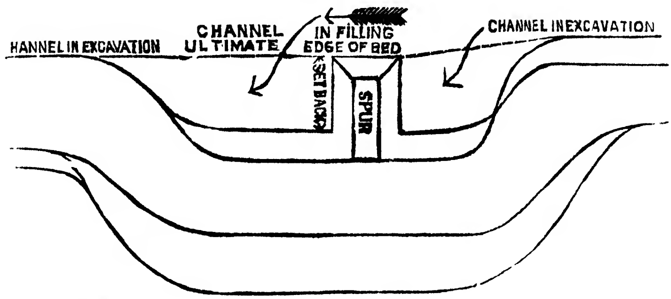
Very wide berms were not a feature of bank construction when the Sirhind Canal, the Lower Chenab or the Lower Jhelum Canals were constructed.

They were generally adopted throughout the channels of the Triple Project.

The embankment or fill is set back from the ultimate designed edge of the channel and the channel is left to berm up to the final designed section.

This deposited berm is nearly water proof. is not burrowed into by rats and it makes the embankment safe.

In long reaches of embankment, earth spurs would be constructed ; these spurs would be made to define the final section required and they accelerate the deposit of berm by the stilling effect on the current.



SILTING TANKS.

On the older canals, where the embankments had not been set back, they were not strong enough for permanent safety and were made permanently safe by the construction of silting tanks.

Along the embanked reach, a subsidiary bank is constructed some twenty or thirty feet distant, the subsidiary bank being joined up to the main bank.

In the main bank two openings are made one at each end of the reach and the flow from the canal is partly diverted and flows between the two banks of the tank.

The area of waterway is considerably in excess of the discharge passing and the consequent stilling effect causes deposit of silt, especially during the season that the river is in flood and the water is muddy.

The silt is deposited nearly up to full supply level. The openings can either be of masonry work or open cuts as necessity dictates.

The inlet should be narrow and deep, full canal depth and the outlet broad and shallow, these conditions inducing the changes in velocity which cause precipitation of silt.

If the silting reach was too long to be silted from one pair of openings it would be necessary to divide it up into shorter reaches.

SPOIL BANKS.

When a large canal has to be excavated to a considerable depth below natural surface, the excavated material has to be thrown into a bank on each side of the canal beyond the patrol

bank. The patrol bank is 2 feet above natural surface and the spoil bank about 12 feet high.

The top of the spoil bank is divided into compartments by dowels and planted with trees.

The practice has been so far to throw the spoil bank contiguous to the patrol bank, leaving only an eight foot or ten foot interval for a drain which is designed to carry the rain water running off the patrol and spoil banks and which delivers the water at intervals of about half a mile to culverts under the patrol bank, or at intervals of 1,000 feet to outfalls through the spoil.

This depends on the direction in which the water can be drained. If the land slopes away from the canal the drainage is through the spoil outwards. If the land slopes towards the canal, the drainage has to be into the canal beneath the patrol road. The culverts deliver the *water* into the canal.

If the plantation on the spoil bank is successful and the dowels on the spoil bank are maintained, rainfall collects in the partitions between the dowels, and the spoil banks remain in fairly good condition.

Should the soil be sandy or otherwise not productive of plantations, the adjacent spoil bank is a source of trouble. The run off on the bare slopes appears always excessive for the drains which either breach across the patrol bank or beneath it undermining the natural soil on which rests the patrol bank.

Costly repairs are necessary; should the repairs not be carried out year by year, the whole of the area formerly occupied by the patrol bank is cut up and becomes an irregular inner slope in continuation of the slope of the spoil bank.

It gets honeycombed or cut up according to the nature of the soil.

All this would possibly be avoided if the spoil banks were placed further from the patrol bank, say twenty feet away, when the drainage has to be passed into the canal.

This would increase the width of the drain space and permit the drain, even when partly silted, to carry the flow off to the culvert without overflowing. The culvert should be of liberal dimensions.

When the drainage is through the spoil, the outfalls should be placed at 250 feet intervals.

When the interval is as much as 1,000 feet as was the former practice, the drain when choked or obstructed overflows the patrol bank and causes in a deep cutting damage which is almost irrepairable.

CHAPTER III.

Masonry Works.

HEAD REGULATORS FOR DISTRIBUTARIES.

Of masonry works across distributary channels, the first in order of position and interest is the head regulator admitting water to the channel.

This consists of a culvert on the upstream face of which is fixed a gate by raising or lowering of which the supply to the distributary channel is admitted or regulated or shut off as may be desired.

The construction of these culverts according to "type" sometimes resulted in a workable arrangement, but too often the type design neglected to take into consideration the conditions governing the passage of the supply from the parent to the distributary channel.

FREQUENT UNSUITABILITY OF TYPE DESIGN.

Certain channels (a large number) even after they were constructed to sections which according to the Hydraulic diagrams should be non-silting ones, would persistently silt up in the first mile or half mile. It was noticeable that those channels would be afflicted in this way in which the level of supply would be only a few inches (if as much) below the water level in the parent channel.

Other channels in which the working head available was one foot or more would never silt in this manner and in some that did not silt the side slopes would have to be protected from erosion for some distance below the regulator.

Such channels would not apparently belie the accuracy of the diagrams. It was observable that channels in which there was plenty of energy in the water coming from the culvert did not silt and *vice versa.*

The cause of the silting was correctly attributed to the design of the regulator culvert and was due to the way in which the water passed from one channel to the other.

The silting was often very troublesome in minor distributaries offtaking from distributaries.

AVAILABLE " HEAD " USUALLY SMALL.

It has been mentioned before that in the earlier construction of canals, command on distributaries was inclined to be in defect, and throughout the whole system there is not much available difference in the working water levels between any one channel and others offtaking from it at the common points.

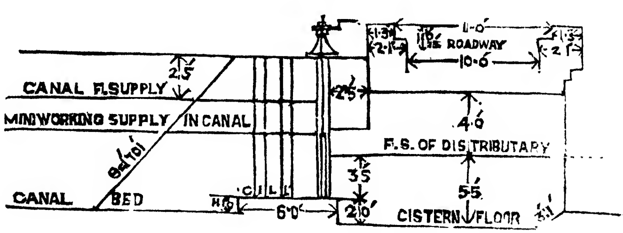
In general, this is the tendency with which such systems are constructed, as they cannot obviously be carried high above the surrounding country.

In spite of the smallness of the available head between parent channel and offtake channel, we find that in the type design of these culverts there are introduced countersunk floors or wells or cisterns meant to destroy the surplus energy of the water falling from the feeder channel so that the banks of the distributary would not be damaged.

In cases where there is available head to be destroyed there is nothing to cavil at in the design. But where every available inch of head was valuable the design was out of place.

LEVEL OF OFFTAKING CULVERT.

Whatever the level of the offtaking channel, the level of the cill of the gate was placed at or near to the bed level of the parent channel so that the diagram of the water passage through the culvert would be as below.



RELATIVE POSITION OF CULVERT.

The direction of offtake was also invariably placed at right angles to the direction of flow of the water in the parent channel even in instances when the general direction of the offtaking channel was skew to that of the parent channel.

The result of these features of the design of gate and culvert is that the issuing stream is dependent on the resistance of gate orifice and culvert and on the head available to overcome that resistance ; and besides, owing to the normal position of the culvert relative to the main stream, no part of the energy of the main stream can be communicated to the issuing stream.

But in cases of silting head reaches, it will be found that any available head is valuable, and even the energy of the main stream should not be dissipated.

The sections given in the Hydraulic diagrams are sections of water channels in steady flow. If silt laden water has to flow down a channel from an imagined still pond, it will need in a certain length of head reach a steeper slope than shown on the diagrams for the same volume of discharge ; along the initial slope the acceleration is generated from zero to the mean required velocity for silt transportation. So it was found that the channels silting in the bed reach silted to a steeper slope than was required by the diagram.

From examination of water levels, the inference was drawn that there was not in these channels sufficient energy in the water after its passage through gate and culvert to cause it to move along the graded slope with non-silting velocity.

The velocity would be slower, silt would drop until the slope was steep enough for the purpose. In dropping the silt, however, a bar was created over which the necessary depth and in consequence a volume of supply could not be passed.

Then was recourse had to repeated silt clearance, but the channel was not an efficient one.

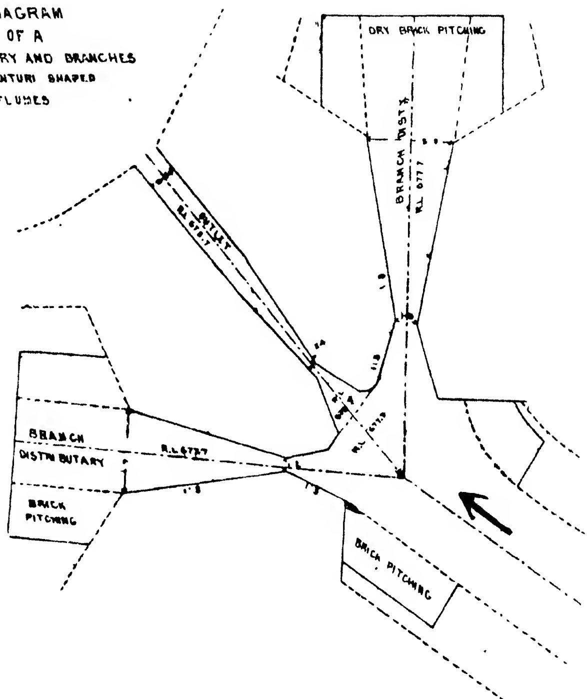
The process of silt clearance was looked upon as an indispensable feature of the maintenance of certain channels.

The first attempts to remove the cause of the silting consisted in the construction of a masonry sill in advance of the gate. It was called the raised sill and was proposed in consequence of the theory that the silting was due to an imagined heavy silt in the water, next to the bed, that is, to the rolling bed silt.

There is ample evidence that the raised cills had no effect in stopping the precipitation of silt. But the theory survived.

In cases where the principle of the conservation of the energy in the water has been applied and the water transmitted,

DIAGRAM
OF A
DISTRIBUTARY AND BRANCHES
WITH VENTURI SHAPED
FLUMES



with as little loss of head as possible, *i. e.*, with gradually applied changes in direction or section of waterway from feeder channel to distributary ; the silting effect has ceased.

In 1916 three papers were published on the design of the head regulators for distributaries and it is interesting to reproduce the views of the authors. These were Messrs. Gibb, Schonemann (now Woods) and Elsden.

THE VENTURI-SHAPED FLUME.

Since the venturi-shaped flume has come into use, many distributary heads formerly provided with gates, especially minor heads, have been replaced by these flumes which can be designed to give the discharge required at the water level usually prevalent in the supply channel. The troublesome human element, the turnkey, is eliminated.

CHAPTER IV.

Bridges, Falls, Flumes.

ROAD BRIDGES.

Bridges on canals are usually constructed of brick masonry. The pattern adopted is the viaduct of arched spans of twenty to twenty-five feet for large bridges and of smaller spans for smaller bridges across branch canals and distributariés.

The arches are usually 90° segments or 75° segments.

UNEVEN NUMBER OF SPANS.

It is preferable to have an uneven number of spans so that the centre of the stream will pass between two piers rather than find a pier in the way, as the central pier tends to collect all the floating matter, especially in small channels.

RAILWAY BRIDGES.

For railway bridges across canals, which are constructed by the railway administration, the pattern usually adopted is the steel girder bridge carried on brick masonry piers.

CUTWATERS.

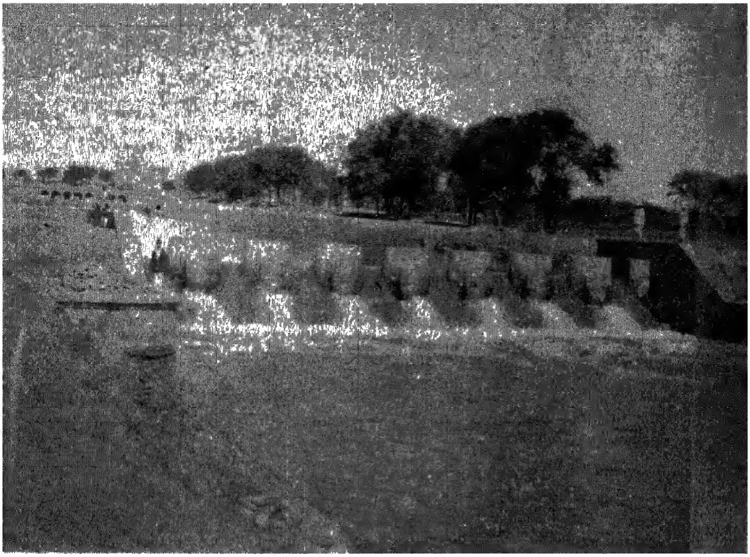
The piers of all bridges are shaped with cutwaters upstream and downstream.

FOUNDATIONS.

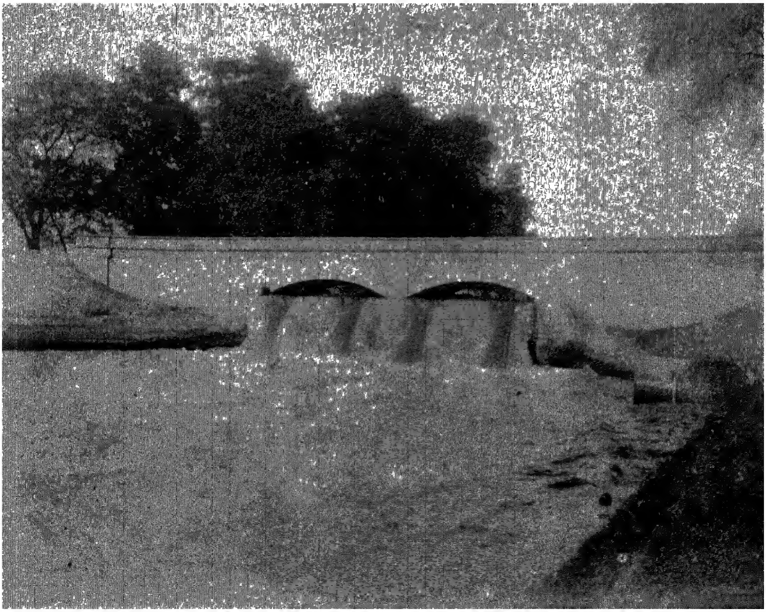
The foundations below canal bed are of rammed concrete. It is not usual to provide heavy protective floors to the foundation of piers and abutments as the velocity for which the canal is designed is such that no erosion of the bed is expected, and there is not in consequence any liability to undermining of foundations.

WATERWAY.

The waterway of bridges is usually designed so that the width between abutments is equal to the bed width plus the depth and the full supply level is 1·0 or half a foot below the springing of the arch.



Notched Fall.



Notched Fall and Bridge.

Latterly, for large canals, the waterway has been taken as bed with plus half the depth, but sometimes the width of waterway has been simply equal to the bed width.

When the canal is large and the depth a small quantity compared to the bed width, the inclusion or exclusion of this quantity is of small account.

As the side slopes of a canal are usually half to one slopes the area of waterway up to the water line in a single span bridge $(b + \frac{d}{2})$ d is exactly the area of the open channel.

When bridges over large canals are constructed the total width between abutments is the sum of the bed width plus the added thickness of the piers and the canal is widened at the bridge site to the extent required.

At bridge sites, the banks and sides of a canal are subject to considerable wear and tear on account of the passing cattle that go to the water to drink.

For small channels say twenty foot bed width and under, girder bridges are preferable to those of the arched type.

The advantages are—

(*a*) minimum clearance possible between water level and bottom of girder,

(*b*) smaller depth of girder compared to rise and thickness of arch,

(*c*) consequently less rise of the roadway and smaller cost of maintenance of ramps and approaches.

At one time in the history of the Irrigation Branch it was usual to construct bridges at road level and to syphon the channels under the roadway.

This method proved very troublesome, in that the waterway got choked.

When a syphon is necessary it should be so designed as to be self-cleansing; for this purpose the velocity through the syphon must be greater than the velocity usually prevalent in the open channel and a small loss of head should be provided for at the syphon in order to generate the velocity.

In order that this loss of head be not misapplied it would be necessary to have smooth approaches, exits and barrels.

FALLS, RAPIDS, FLUMES.

In order to avoid erosion of the bed and sides of canals, they have to be designed with slopes, which are, in the Punjab, flatter than the normal slope of the country.

At every few miles, therefore, a fall has to be interposed in the bed slope and the water passes from one level to another through a water-fall, usually termed a fall.

At the section where the abrupt change of bed occurs, a specially designed masonry work has to be constructed in order :

(*a*) To keep the bed of the upstream reach to the designed level and to prevent erosion and retrogression of the bed levels.

(*b*) To deal with the disruptive effect of the falling water.

TRAPEZOIDAL NOTCHES.

The early irrigation engineers conceived the notion that in order to maintain the channel in good order, or good regime, it was desirable for the water surface to be parallel to the bed at all stages of the supply in the reach between fall and fall ; and to achieve this, designed trapezoidal notches of the full depth of the channel upstream through which the water passed at the falls.

These trapezoidal notches were close enough to the form of notch, which, theoretically, fulfilled the required conditions.

On the main canals and large branches, this form of notch is as useful as any other, and is at any rate harmless.

DEFECTS OF TRAPEZOIDAL NOTCHES FOR DISTRIBUTARIES.

The design however was made to prevail for all sizes of channel. On small channels, it may be imagined, the notch became very narrow and was easily blocked by floating debris or could be easily obstructed when it served the purpose of the cultivators to do so.

An obstructed notch has often caused a breach of the banks in the reach above it, and also causes interference with the proper distribution of water.

Again, during a period of mediocre demand a distributary has occasionally to be run with a supply about 25 per cent. less than the full capacity to avoid breaches in the lower reaches.

But this supply has, as may be understood, to be passed into the outlets at nearly the same level as the full supply. The levels of the fields do not change.

WIDE RECTANGULAR NOTCHES.

The form of notch therefore more suited to a distributary has to fulfil three conditions—

(*a*) unobstructiveness to floating debris,

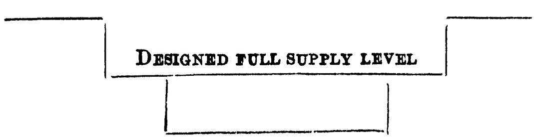
(*b*) not easily interfered with, without detection,

(*c*) small variation in supply level for variable capacity.

The wide rectangular notch with a broad crest is preferable under these conditions and is besides valuable as a meter.

On distributaries, the trapezoidal notches are being replaced by wide rectangular notches.

Notches are constructed with a ledge at full supply level in order to indicate at a glance to an inspecting officer whether the full supply discharge is being passed at the notch.



Falls which would be drowned falls when designed with a trapezoidal notch of the full depth of the channel upstream become free or nearly so when designed as wide rectangular notches and are easier to calculate accurately as they discharge as free falls even when drowned up to 66 per cent. of the depth on the crest.

To deal with the disruptive effect of the falling water, the universal method is to let the water drop into a basin or well and to protect the sides of the channel with dry brick or stone pitching for a short length.

Generally the disruptive effect has been in excess of the provision made to deal with it and we find eroded channels beneath the falls and regulators of all the canals in the Punjab.

Erosion of the bed beneath falls has usually been overcome, it is the more dangerous as it would endanger the foundations.

The destructive energy in the water although diminished to an extent sufficiently to render all foundations safe has, however, not been neutralized to the extent required to prevent erosion of the sides of the channel.

The energy and consequently destructive effect of the falling water is dependent on the height through which it falls and on the volume passing per foot run.

The notched falls were provided with lips which had the effect of causing the water to fan out to some extent after passing the minimum control section.

The neutralising effect is dependent on the depth of the water cushion beneath the fall.

When falls were first designed and built in the Punjab the effect of the fall on a bottle partially filled with water was observed. This bottle was suspended from a rope and it was determined that the bottle did not reach within $1\frac{1}{2}$ feet of the cistern 7·0 deep in which the experiment was conducted.

From repeated experiments an empirial formula was adopted.

$x = \sqrt{h}\,\sqrt[3]{d}$ where x is the required depth of the cistern,
h, the height of the fall and
d, the depth in the channel,

upstream of the fall.

Other formulæ of the same nature have been advanced or adopted from time to time.

The length of the cistern (in the direction of flow) was made $3x$.

From observations on the natural falls in soft sandstone which are to be found in the Pabbi hills, it was observed that the falls in the natural channel provided for themselves water cushions which, very roughly, were in correspondence with the formula, but that the length of cistern was about twice as great in the natural fall, as would have been allowed by the formula.

RAPIDS.

Instead of falls, the Upper Bari Doab Canal was provided with several pitched rapids or reaches of the canal in which a steep pitched channel enabled the water to pass from a higher to a lower level.

THE PITCHED CHANNEL ON THE UPPER SWAT CANAL.

Similarly at Durgai on the Upper Swat Canal the canal flows in a pitched channel with a slope of 1 in 250 for four miles above Durgai. The bed of the pitched channel besides having a steep slope has a fall of 1·0 at intervals of 50′, 100′, or 200′ to suit the slope of the country.

The small distributaries which flow down steep country in each side of the central table land of the Upper Swat Canal, have channels which are concrete-lined flumes divided up into short lengths by vertical falls about 1·0 in height.

The height and distance apart of the falls depend on the relative steepness of the country.

The wide rectangular notch is the most useful type when a free fall is available.

At such points of a distributary where a fall has to be interposed, although but a drowned fall, and where it may be desirable to have a notch as deep or nearly as deep as the supply depth in the channel, a rectangular notch with splayed approaches is now adopted.

This type has come to be considered as a correct design for bifurcations on distributaries.

CHAPTER V.

Materials used.

MATERIALS.

Owing to the cost and difficulty of carriage, the engineers constructing the earlier irrigation works in the Punjab had to be content with the simple materials which were obtainable locally.

BRICKS.

Bricks and lime, locally burnt, stone and timber nearly exhausted the list.

Iron and steel were sparingly used.

On joining the irrigation service, the engineer used to be initiated into the details of local brick burning and of lime manufacture from *kankar*, the nodular lime stone found in the plains of the Punjab.

Bricks are usually burnt in a continuous kiln known as " Bulls " from the name of a contractor who used them.

The kiln consists of two long parallel trenches connected by semi-circular ends.

The size of the brick used in the Irrigation Branch is larger than usually found elsewhere. It measures $10'' \times 4\frac{7}{8}'' \times 2\frac{3}{4}''$, four courses go to the foot and the brick weighs 10 pounds.

It is usually estimated that to burn 100,000 bricks (the usual unit in burning operations) the fuel requirements are twenty tons of slack coal and a hundred maunds of fuelwood.

The cost of bricks has doubled in the Punjab during the past twenty years. They cost Rs. 9 per thousand in 1905 and now cost Rs. 18 per thousand.

The price of bricks in towns is usually greater than their cost to the Irrigation Branch which usually manufactures bricks at very economical rates.

Bricks are classified departmentally into three classes, excluding underburnt or *pilla* bricks.

LIME.

The nodular limestone of the Punjab produces, when burnt, a hydraulic lime or natural cement. Although the tensile strength

is small compared to that of Portland cement, the mortar formed from *kankar* lime or a mixture of *kankar* lime, white lime and *surkhi* (brick dust) has the requisite strength and has been used in all the works constructed by the Irrigation Branch.

Kankar lime is generally used neat. When mixed with *surkhi* only, the *surkhi* acts as a diluent and cheapens the mortar.

When white lime is mixed with *kankar* lime, the strength and hydraulicity of the *kankar* lime is improved.

Kankar lime, as obtained from ground burnt *kankar* contains an excess of burnt clay, and for this reason it is improved by an admixture of white lime.

A mixture of white lime, *kankar* lime and *surkhi* (brick dust) has for many years been the standard mortar in use in the Irrigation Branch of the Public Works Department, and experience has shown it to be very strong and durable.

The mixture was subjected to extensive tests at the time of the construction of the Headworks at Khanki and Rasul.

KANKAR LIME MANUFACTURE.

Kankar lime is burnt either in clamps or in kilns which may be continuous or intermittent.

Clean raw *kankar* in three inch layers, spread evenly through the kiln, or clamp, alternates with the slack coal (dust coal) used for burning.

The proportion of coal used is about ½ a ton per hundred feet of raw *kankar*. This proportion is measured and spread evenly over the *kankar* layer.

Burning in clamps is a more expensive process than burning in kilns owing to the increased amount of fuel necessary to overcome the heat lost by radiation and owing to the proportion of unburnt *kankar* on the outer surface of the clamp.

Clamp burning is generally resorted to when the quantity required is comparatively small.

The burnt *kankar* is ground in pulverising mills and the lime ground and screened to the required fineness is ready for use. The finer the lime is ground, the better the mortar obtained, as chemical action takes place readily between fine particles.

Kankar lime has, as a general rule, been manufactured departmentally for use on the works of the Irrigation Branch.

From white lime hydraulic mortar is obtained by admixture with the correct proportion of finely ground burnt clay or brick dust, and this mortar has also been largely used in the Irrigation Branch.

White lime, it has been mentioned, added to *kankar* lime improves the latter, and as a further corrective to the white lime some brick dust is also added.

WHITE LIME.

White lime has been largely purchased from the manufacturers as well as manufactured departmentally.

The quality of the white lime obtainable in the market is good.

Limestone is available from the Salt Range and elsewhere in the Punjab and manufacturers erected their kilns at Railway Stations whence the finished product was easily railed to destination.

Departmental manufacture has been undertaken at Baghanwala in the Salt Range and also at Bahawalnagar for the work of the Sutlej Canals.

BRICK DUST (*SURKHI*).

Brick dust is manufactured by grinding brick bats in a disintegrator and screening to the required fineness.

SUITABLE MIXTURES. TESTS.

Tests were carried out at Rasul in 1899 on various mixtures of *kankar* lime, white lime, and *surkhi*. The mixtures tested were—

Kankar Lime.	White Lime.	Surkhi.
40	20	40
50	25	25
60	20	20
40	10	50

The mixture 60, 20, 20 was selected as the most useful on account of—

(*a*) its quick setting property ;

(*b*) its adhesive property ; 41 lbs./square inch at 2 months ;

(*c*) it was also reasonable in price ; Rs. 23 per cent. c. ft. in 1899.

These mixtures showed a breaking strength of 100 lbs./square inch after 60 days.

A mixture of 90 parts *kankar* lime and 10 parts white lime gave the best tensile strength results, *viz.*—

74 lbs./square inch after 7 days.

108 lbs./square inch after 21 days.

This mixture was not preferred to the 60 : 20 : 20 on account of the extra cost. It cost Rs. 26 per cent. c. ft. After a year the mixtures gave results varying for individual tests between 210 and 250 lbs./square inch, the most consistent being the mixtures 50 : 25 : 25 and 40 : 10 : 50 which were of an average strength of 235 lbs./square inch.

For the construction of the masonry works on the canals of the Triple Projects, the *kankar* lime mixture 60 : 20 : 20 or 3 : 1 : 1 was generally used.

CEMENT MORTAR.

For the construction of the masonry works on the Sutlej Valley Canals cement mortar has been generally adopted.

Cement is now produced in the Punjab at Wah near Hasan Abdal and the cement mixed with local river sand gives the requisite hydraulic mortar. The fact that only one of the constituents, *viz.*, the cement, has to be carried and stored makes simpler the problem of the mortar supply.

The cement is produced of more uniform strength than ever the *kankar* lime could be made.

The strength of modern Portland cement is compared in the table below with the strength 20 and 10 years ago—

Breaking strength in lbs./sq. in. of briquettes of neat Portland cement.

1905.	*1915.*	*1925.*	
350	450	750	After 7 days.
450	550	850	„ 28 days.

The high strength of modern Portland cement makes it possible to use mortars of 1 : 8 cement sand.

The following table showing the results of tests carried out in the Irrigation Branch on mortar made of Portland cement and sands of the Sutlej river is interesting :—

Average tensile strength in lbs. per square inch for mortars of Sutlej river sand and Wah cement.

Mortar.		Islam.		Sulemanke.		Ganda-singhwala.		Rupar.		Standard.	
		7 day	28 day	7 day	28 day	7 day	28 day	7 day	28 day	7 day	28 day
1 : 3	..	343	447	351	594	289	497	344	553	540	604
1 : 4	..	242	424	259	471	230	422	266	436	334	394
1 : 5	..	191	337	189	364	177	335	206	388	260	267
1 : 6	..	153	267	150	281	122	262	176	334	206	204
1 : 7	..	133	235	118	243	106	226	133	240	189	179
1 : 8	..	107	210	90	202	92	172	116	217	149	148

Standard sand is of a size that passes the 20 mesh, and is retained on the 30.

PORTLAND CEMENT.

The following mixes were being adopted for the concrete of the headworks on the Sutlej Valley Project :—

1 cement : 4 sand 9·6 aggregate for the lower layer of concrete floors;

and 1 cement : 3 sand 7·5 aggregate for the upper layer of concrete floors.

Such concrete is mixed in mechanical mixers, the amount of water being automatically regulated to give the strongest concrete.

Modern investigation shows that concrete should be mixed as dry as possible in order to obtain the best results and the quantity of water added is as important as the correct grading of the mix.

STONE.

Stone used on the canal works in the Punjab has been obtained in the greater part from the following quarries :—For the Sirhind Canal from Nalagarh on the Siwalik Hills ; for the Lower Jhelum Canal from Baghanwala in the Salt Range.

The Baghanwala stone is a light coloured limestone capable of taking a fine finish.

For the construction of the Upper Jhelum Canal and other canals of the Triple Project, quarries were opened at Taraki in the hills between Jhelum and Rawalpindi.

The Taraki stone is dark grey sandstone harder than Baghanwala stone.

For the construction of the works of the Sutlej Valley Project, the Nalagarh quarries have been reopened and extensively worked.

Stone has also been obtained from Baghanwala and from Delhi.

Pitching stone is also quarried from the Sangla Hill close to the Rakh Branch of the Lower Chenab Canal, and from the Chiniot Hills.

The material from Sangla is red shale, suitable for pitching, and it is used at Khanki which is within reasonable distance.

ASHLAR.

Ashlar is quarried at Hassan Abdal above Rawalpindi.

BOULDERS AND SHINGLE.

Large boulders from the river bed have been used for pitching the slopes and bed of the canals and for the protection of embankments wherever these could be economically used.

Shingle has largely entered into the composition of concrete, sometimes broken and sometimes unbroken if obtainable of the correct sizes.

TIMBER.

Timber is floated down the rivers from the forests in the hills and is obtainable from the depôts at canal headworks and at other large towns on or close to the rivers.

For example : at Jhelum, Wazirabad, Lahore, Phillaur Beas, Multan.

There are four varieties of timber usually available. These are Deodar, Chir, Anandar or Kail and Partal.

DEODAR.

Deodar (cedrus deodar) is the most useful. It is more durable than the other kinds.

The wood has a fine light brown colour, is fragrant, slightly oily and compact.

It does not warp or split and is the most prized wood in the Punjab for all sorts of construction.

ANANDAR OR KAIL.

(Pinus excelsa). The wood is light brown, compact and even grained ; it ranks next to deodar in durability.

CHIR OR CHIL.

(Pinus longifolia). The wood is white, easy to work and is commonly used as it is cheaper than deodar, but it is not durable.

PARTAL.

The timber obtained from the silver fir or spruce. It is the cheapest and the least durable.

CHAPTER VI.

PLANTATIONS.

The avenues on the canal banks and the plantations on the spoil banks which seem to show that the Engineers constructing the canal were keen on aesthetic effect, are not really there for the sake of improving the scenery. They have a utilitarian value apart even from their value as a source of fuel.

The trees which overhang the banks of canals and distributaries protect those banks from the direct effect of rainfall and also produce the shade which allows grass to take root.

Were it not for the protection afforded, the banks would year by year be denuded by rainfall and the cost of maintenance would be excessive.

The spoil banks also have to be planted with trees, in so doing the area covered with spoil is rendered productive and at the same time the effect of rainfall on the banks is mitigated and the destructive effect of the flow off is diminished.

This is illustrated by comparing the effect of rainfall in reaches where the spoil is covered with plantations with the effect on spoil banks where there are no plantations.

In the latter case the rain running off the top and slope of the spoil bank towards the canal causes large cuts and breaches in the patrol bank.

Within twenty years the plantations come to maturity and the timber and fuel become valuable.

Except in a few localities, in proximity to markets, the fuel and timber are not readily marketable and only near markets is it possible profitably to adopt a continuous programme of felling and restocking.

The trees which are usually grown are the Kikar (acacia arabica) and the Shisham. They are easily grown. The former is valuable as fuel and the latter as timber and fuel.

PART III.—IRRIGATION PRACTICE.

CHAPTER I.

Regulation.

DEFINITION.

Regulation involves the issue by the Regulating Officer of such orders as will enable the supply to be distributed safely and economically.

These orders are based on a knowledge of the water levels recorded throughout the system of canals and on intimation of indents for water supply made on the Regulating Officer by other officers responsible for the distribution of water.

At daybreak (6 A.M.) all gauges are read by the gauge-readers and these are collected by a staff of telegraphic signallers and tabulated on a printed form.

This printed form is generally ready and delivered to the Regulating Officer by 8 A.M. By this time he will have received or is already in possession of indents for a diminution or an increase of water supply at certain points of the system and the Regulating Officer is in position, by correlating gauges and discharges, to issue such orders as will correct any errors in the distribution or will bring about a redistribution of the water-supply according to requirements.

SAFETY.

It is very important that the supplies in the channels should be within the safe capacity of the channels. The officers incharge acquaint themselves with the gauges which represent the maximum safe capacities and on making over their charges acquaint the next incumbent with these details.

Generally, at important stations these details are well established and are contained in printed pamphlets for local use.

ESCAPES.

At certain parts of the system there are escape channels leading to outfalls in the river or to reservoirs. It is the duty of the gauge-reader at the escaping stations to see that the safe

gauges in the channels are not exceeded. Surplus water is passed into the escape.

It is the duty of the Regulating Officer to notice at the time he receives the gauge slip whether the gauges are safe ones or not. An excessive supply of water may reach certain points of a system through inattention on the part of the gauge-recording staff, especially during the night, or through heavy rain or errors in distribution. The Regulating Officer then attempts an adjustment of the supply to avoid a breach in the banks of a channel.

Gauges are read three times daily: at daybreak, noon and sunset (6 P.M.). The gauges are recorded in a register by the gauge-reader and also in the offices.

RECORDING OF GAUGES AND DISCHARGES.

At certain stations the discharges corresponding to the gauges are tabulated and an account of the water passing certain important stations in a system is kept. The maintenance of the gauge registers is considered an important duty of certain members of the staff.

The Zilladar (an officer of the revenue staff) and the Sub-Divisional Officer are ordered to keep the registers in their own handwriting. In the Divisional and Circle offices special clerks are allotted to this duty. Ten daily and monthly accounts of the water used are made up and the monthly totals of the water used on distributaries are incorporated in the revenue accounts. The water used is compared with the area irrigated and the average depth of water applied is inferred.

The water allowed to escape has generally to be accounted for. There are seasons of the year when the water in the rivers is much less than what can be utilized and evidently leakage at escapes is not to be countenanced. At such times the escapage of water to correct errors of regulation is considered a serious offence. The distribution of the water has to be carefully watched by the officers responsible for it.

ROTATIONAL FLOW OF CHANNELS.

During the season of low river supply which corresponds roughly with the winter, as the supply in the river is less than the full capacity of the canal, the branches of the canal and the distributary channels offtaking therefrom are caused to flow in a pre-arranged rotation.

Sufficient experience has been obtained to enable the best rotation to be fixed and the time table is approved by an officer of administrative rank. The other officers and the rank and file have then no discretion but to follow the time table.

Under circumstances where no time table is pre-arranged the local officers, the Divisional or Sub-Divisional Officers, as may be the case, use their discretion in the distribution of the water.

They are protected in the execution of their duties by certain sections of the Canal Act which deal with the subject and by Standing Orders issued for the general guidance of officers.

Since the inauguration of the Triple canals in the Punjab, a careful forecast of the river supplies is prepared and the distribution of the waters of the rivers Jhelum and Chenab is arranged among the canals issuing from these rivers ; these are :—

Upper Jhelum, Lower Jhelum, Upper Chenab, Lower Chenab, Lower Bari Doab.

The combined irrigating capacity of these canals amounts to 29,000 cusecs.

Regulation at the headworks of a canal or at a level crossing is usually more complicated than elsewhere. Printed pamphlets of rules framed as the result of past practice are usually available.

CHAPTER II.

THE DISTRIBUTION OF WATER FOR IRRIGATION.

The subject is one with many difficulties. It has a wide scope owing to the varied nature of the irrigation done in the Punjab.

The distribution of water has given much labour to those concerned with it in its development from a crude and simple system to an organized science with an attempt at automatic working where possible.

The distribution is that by outlets from distributaries and as there is some difference of detail in the distribution on—

(*a*) inundation canals,

(*b*) on new perennial canals,

(*c*) on well-established perennial canals,

each of these will be considered in turn.

INUNDATION CANALS.

The conditions here are that a tract of country has to be supplied with water for approximately four months in the year when the level of the water in the river is high. There is plenty of water in the river and the canals are excavated of sufficient width to give to the land a heavy and frequent watering.

Except at the beginning and end of each flood season, there is usually no great difficulty in dealing with the water distribution, because the water is plentiful.

On account of the comparatively low duty, outlets on inundation canals are often of large capacity especially if they have to supply large *chaks*. Outlets may discharge as much as 10 cusecs.

The type of outlet which is the most suitable is the weir, either the overflow weir, or the comparatively narrow lateral constriction, with splayed approach and exit.

But other types of outlets, for example the Kennedy gauge outlet, could with advantage be used in certain reaches of long canals.

The consistent effort at correctly fixing outlets on inundation canals is of recent date. Usually, past practice has been either the absence of a controlling outlet, or there has been merely a culvert (masonry or wooden pipe) through which the irrigator took just as much water as his watercourse could carry when silted or when silt cleared.

The beginning and end of the irrigating season have been mentioned as periods of difficult distribution. Owing to the state of the river there may be at such times in the canal a discharge not greater than a quarter of the capacity of the canal, and whatever be the type of outlet, special orders for the disposal of this small supply will be called for. The water at such periods is of exceptionally high value.

Again in certain long canals unless correct principles are adopted, the disribution will be faulty.

THE DIFFICULTIES.

The general difficulties met with are that certain parties situated generally in the upper reaches of a canal take off a quantity of water considerably in excess of what would be due on an even distribution, and it is surprising to find how much more can be so taken. The excess water saves labour in the maintenance of watercourses, so that however much is wasted, none is missed. Attempts to reduce this excess water are resisted by those who foresee extra labour in watercourse maintenance and also a more limited supply during the periods of restricted supply at the beginning and end of each irrigating season. If this excess water has been allowed over very long periods the beneficiaries have obtained a *defacto* lien on it and it is not without a prolonged struggle that the equal rights of all the irrigators can be established.

The silting watercourse is the cause of other difficulties in distribution. Such a silting watercourse when cleared, has been known to draw off as much as three times its legitimate supply, and several such watercourses will heavily tax the supply due to other watercourses lower down a channel.

There comes a time, when owing to the want of foresight on the part of the shareholders of the silting watercourse in disposing of the silt cleared, the cost of silt clearance becomes heavy and

troublesome owing to the labour involved. They would obtain a fresh lease of life if the high banks of silt were spread out by the expenditure of some capital.

This, however, they are unwilling to do as there is a cheaper alternative, namely, the excavation of a fresh head reach through land often not theirs, or which they do not trouble to purchase.

There are many watercourses with three or four of these head reaches disfiguring the landscape. The correct solution then appears to be to resist the request for a change of head reach until the shareholders agree to the installation of a weir outlet which will control their supply.

In the absence of such a control a fresh head reach will permit the watercourse to overdraw for a number of years to the detriment of the supply to other villages the watercourses of which offtake lower down the canal or distributary. The pipe outlet, a culvert of either wood planks, metal pipe or brick masonry is particularly unsuitable to the inundation canals on account of the large discharges involved and the length of bank in which they have to be laid. They have caused mounds of silt to be formed about them throughout the inundation canal systems. They were probably used as being the cheapest form of outlet ; other forms involve more masonry work and are consequently more costly ; but if the water is worth distributing, it is worth the cost of a well designed outlet.

All the inundation canals, their distributaries and branch distributaries tail off into two or three large watercourses issuing from a common point ; as the land served is not all at the same level it is important that control weirs be constructed at these points, and to some extent this has been done within the last decade.

NEW PERENNIAL CANALS.

The distribution of water on a perennial canal which is under process of development has difficulties of its own to which general remarks are not easily applicable. Conditions are bound to vary considerably and individual attention is required.

Even supposing that careful surveys would indicate the correct location of outlets and alignments of watercourses, considerations alien from physical ones might require a change in alignment of watercourse or position of outlet.

While it will be necessary to encourage the cultivators by giving them every assistance, it will be necessary to resist the selfishness of individuals who give no thought to the general welfare of the community.

Unless it is certain that the position of the outlet will not be disputed, it will be preferable in the first years of a canal to have outlets which are easily transported in preference to masonry weirs. The Kennedy gauge outlet is an advantage under such conditions ; an ordinary length of steel pipe or wooden shoot is the outlet which has been most commonly used, in spite of the disadvantages connected therewith, and this usage is only explicable as the result of inherited custom.

The difficulties met with in overcoming individual rapacity can hardly be exaggerated. A new canal must resemble a newly discovered gold field in some respects. The first settlers need a good deal of water for a start, the channels constructed for more advanced conditions are large enough to allow plenty of water and quick advantage is taken of it. But it takes very few seasons for land in a popular part to be covered with settlers and as the channel is no larger than before the supply to individuals becomes more restricted.

DISTRIBUTION OF WATER ON WELL-ESTABLISHED CANALS. REMODELLING.

It would be well to remember when dealing with this subject that art is long, perfection not easily achieved.

Some twenty years ago, it was realized that all was not well with the distribution of water. Canals were not then as numerous as they are now but the value of the water began to make itself felt.

The efficiency of the canal systems was calculated and much waste was discovered. Then was recourse had to remodelling.

It was necessary to check the waste and so to utilize the valuable water as to increase production and prosperity if the engineers were to justify their presence.

This had to be done in the face of opposition raised by individual and sometimes by communal interests.

Not that the prevention of waste aimed at penalising individual effort or upsetting establishment arrangements, nor even at restricting the area habitually irrigated, but it certainly involved

new conditions to which the cultivators were unaccustomed, of which they were diffident as they are diffident of any efforts involving co-operation.

One can have every sympathy with their attitude which only education in the new methods to be tried would succeed in changing.

More often than not distribution of the water as proposed under the remodelled conditions would increase the area irrigated, but it would certainly involve more individual labour and attention to detail.

It must be remembered that the remodelling aimed at waste prevention ; to the district the results would be valuable.

There must have been individual cases where abnormal benefits secured under the conditions which permitted the waste would be curtailed under the remodelled conditions.

But the results achieved have been a justification of the work done in waste prevention.

The principles generally adopted were that a supply of water large enough to be manageable was to be allowed for each outlet. This is about 2 cusecs. This is given as an average figure. The outlet would serve the properties of a group of shareholders in the outlet ; the shareholders would belong to one village community or to two or even three such adjoining communities ; each shareholder is entitled to the flow of water in the watercourse for a length of time in proportion to the area of his holding.

The adoption of as large a supply as is manageable for an outlet was a contrast to the previous method of distribution in which as far as could be arranged every cultivator attempted to have an outlet for his property. The number of outlets would then be large and each individual outlet would give but a small discharge.

The cultivator had then the advantage of not being interfered with during his watering, which he could do at leisure.

The disadvantages were great waste and unequal distribution. Waste in one direction and scarcity in other directions.

One result of remodelling has been the supersession of many of the minor distributary channels.

Outlets could generally be placed in the major distributaries instead of in the minor distributaries, with advantage to the

irrigating cultivators. Minor distributaries became altogether obsolete or were used as watercourses for the more distant villages.

As a result of the remodelling, the total number of outlets on a system would be greatly reduced, and great improvement effected in the distribution on long channels.

The type of outlet did not improve as fast as the work of remodelling. Authority has not yet given categorical acceptance to any kind of outlet. The remodelling was usually done maintaining the existing form of outlet which is a culvert in the bank.

This type of outlet does not ensure a uniform discharge at all times as it is very sensitive to changes of water level in the watercourse. When all the outlets begin simultaneously to overdraw as a result of watercourse clearance, the cumulative effect at the end of a long channel is troublesome. There is serious shortage.

But the reduction in the number of outlets, while reducing the number of possible errors and the effect thereof was directly beneficial to distribution.

The development of outlets will be discussed under a different chapter.

DUTY.

When remodelling is undertaken on a well established canal advantage is taken of the circumstance to revise the figure for the duty of water, if practice shows that the figure adopted at the initial design or at the last remodelling is subject to improvement. At the same time the effect of irrigation on the country generally is taken and, if required, a change in the sanctioned percentage of culturable area to be irrigated would also be proposed.

In such a case restriction of irrigation might be proposed. As an illustration, a case occurring on the Lower Chenab Canal is mentioned.

In 1914 it was found that the country in the Hafizabad Tehsil of the canal was showing signs of waterlogging, then attributed to irrigation, but really due to intense rainfall and poor drainage.

Not every landlord was adversely affected, but the steps to be taken would affect a larger number than those needing immediate relief.

The practice was adopted of calling up the people of the villages interested and of offering them either irrigation during the currency of one crop only (the Kharif crop) or the choice of a comparatively low figure for the yearly permissible percentage of irrigation. The latter alternative was chosen and the channels remodelled accordingly.

This is mentioned as a case in which a distinct restriction of irrigation, for a good reason, was an object of remodelling.

Very likely even with the reduced supply the area irrigated would tend to reach the previous figure owing to the greater economy in the use of the water which the cultivator would practice.

This final result must not be taken as defeating the object in view. From the percentages fixed the quantity of water to be allotted to certain areas is calculated from well-known principles, which govern average conditions, but it is optional with the cultivator to diminish the depth of water applied to the soil in any one season and to extend the area to which it is applied.

It has been determined that small depths of water applied for irrigation have no detrimental effect on the soil, excessive depths and wasted water may have.

STABILITY DESIRABLE.

It should be noticed that as there are many difficulties to overcome in remodelling a channel so as to remove all the defects, it will happen that a scheme even though well conceived may leave much undone. With the object of still further improving the distribution, a further scheme might be advanced after a few years.

The object of the scheme might be very praiseworthy especially under circumstances where the scarcity of the available water supply would necessitate great economy in its use and a rigorous elimination of any tendency to waste. But these remodellings must involve to certain cultivators a change of conditions; and recurrent changes affecting conditions of land tenure are not advisable, while stability is a desideratum. Although waste is to be checked changes should be introduced after careful consideration is given to all the circumstances involved.

CHAPTER III.

Outlets.

GENERAL.

It may be wrong to ascribe to a part of a system importance over another part or other parts, but the outlet of irrigation systems, such as that of the Punjab has always appeared to those engaged in the work to be the pivot around which the other parts revolved.

Perhaps that is because on those systems, the outlet was the part which required most attention and one could imagine a system where the outlet would be the cause of very little trouble and some other part would claim prominence as being the object of constant care.

It has to be admitted that the outlet has this peculiarity that here the control over the water passes from the hands of one party to that of the other. The supplier has carried the water for some hundreds of miles it may be, and at the outlet the goods are delivered to the client.

Under the circumstances in which water is supplied in the Punjab by the irrigation branch of the Engineering service, to the cultivators, the outlet which did its work as it should was the only test which the cultivator could apply to the scientific ability, and the integrity of the officers or the preciseness with which that branch was able to do its work.

Discontent and heart-burning among the cultivators can always be attributed not so much to the deficiency of the supply (a sure cause of trouble) but to the unequal manner in which the deficiency would fall on the community.

In communities so closely connected, this phenomenon is natural.

DEFINITION OF AN OUTLET.

We will understand what an outlet should be when we say what it has to do. People have held and might still hold different views about what it should be. It may be stated, however, that in general an outlet should discharge constantly a well defined quantity of water from a distributary or departmentally controlled channel into the cultivator's watercourse.

An older view was that the outlet should discharge into the watercourse a quantity of water proportionate to the quantity in the distributary. That was in the days when the quantity in the

distributary was permitted to fluctuate largely. Modern opinion prefers the distributary to be a channel without any fluctuation of supply during the period of flow.

WORKING CONDITION.

In order that an outlet discharge a constant supply of water, the hydraulic condition necessary is, at least, a constant level on the supply side; this would be for automatic working, that is, for an outlet which is not attended to.

Modern practice demands a constant level on the supply side; this is, under modern conditions, generally obtainable.

A variation on the delivery side is inseparable from the conditions of supply, which are :—

(*a*) Variations in the level of the land to be irrigated, and

(*b*) Variations due to alternate deterioration and cleaning out of the watercourses.

On the perennial canals of the Punjab, where the water has to be strictly accounted for and where the distributaries take a supply which not only can be kept constant but which must not be exceeded, there is an obvious necessity for an outlet discharging correctly; if an outlet takes too much other people are deprived, several such outlets will cause serious deprivation at the end of a distributary commonly referred to as the "tail," in contrast to the head which is the end at which water is admitted.

The supply of water to the tail of a channel has been the crux of the distribution and it is always a criterion of the accuracy of the work done.

NEED FOR ACCURATE OUTLETS.

As a practical consideration and in the total absence of any tests to prove the contrary, it may be asserted that a cultivator would not appreciate a variation of 10 per cent. in the supply he receives; this might then be considered as the order of precision to which we might immediately aspire.

But the old form of outlet which simply consisted of a smooth culvert through the bank was extremely sensitive to small variations of head especially at the low heads which were usually prevalent. It is only necessary to write on two lines values of h and $\sqrt{h}$ to make this clear; for variations in h the discharge varies as $\sqrt{h}$.

h	0·025	0·05	0·075	0·1	0·2	0·4	0·6	0·8	1·0
$\sqrt{h}$	0·16	0·23	0·28	0·31	0·44	0·63	0·77	0·9	1·0

Roughly for a variation from ¼ of an inch of head to one inch and a quarter the discharge can be doubled, again doubled if the head is increased to five inches.

Owing probably to lack of confidence in design, earlier designers did not construct the distributaries to give enough "working head" to the outlets and an improvement in this respect is characteristic of modern design. Evidently, if every distributary could be so constructed as to permit a "Free fall" through every outlet, the problem of distribution could be much simplified owing to the constant discharge obtainable through a culvert discharging with a free fall.

A distributary is not so constructed on account of the unnecessarily heavy expenditure which would be involved in construction and maintenance.

It is not difficult to understand that, with only small "working heads" available, the variations in the discharges taken by outlets would be considerable and consequently the amount of water reaching the tail of a distributary serving several outlets *en route* would be still more variable. A very undesirable state of affairs.

One can imagine a distributary fitted with plain barrel outlets of such a size that the outlets would draw a correct supply only when the watercourse was at its maximum efficiency or in other words such small outlets as would never overdraw.

The supply of water to the tail would be not only assured, but the probability is that there would be more water reaching there than could be dealt with and the amount of work and hardship thrown on the cultivators dependent on the outlets not situated at or near the tail would be considerable. The greatest objection to such an arrangement is the impossibility of determining accurately the size of the outlet that would be required, and all things considered the departure from the ideal distribution would be greater under the arrangement postulated than under arrangements usually prevailing where the shortage is thrown on the tail.

RECTIFICATION OF DEFECTIVE SUPPLY AT THE TAIL OF A DISTRIBUTARY. TATILS.

In practice then, the errors of supply to a number of outlets fixed in a distributary system accumulate and show an effect in the supply reaching the tail of the channel. In the majority of cases known, the supply there is defective, when there is most demand.

The method adopted to rectify this defect is a ready practical one, but its application leaves something to be desired.

It would appear easy of application, but the results are pernicious. The consequent interference with the husbandry of a tract of land is considered to be so troublesome that tatils are hated by the farmer.

The method consists of the closure of a certain number of outlets daily, the discharges from the closed ones combining to supplement the defective discharge detected at the tail.

It is necessary to do this with accuracy. First are determined the discharges of all the outlets on the distributary and then the outlets which overdraw and those which are supplied in defect are discovered. The amount to be made up is known and of the outlets which overdraw certain are selected for closure daily.

The administrative procedure in connection with the closure of outlets in this manner consists in the issue of notices to the cultivators concerned that the outlet should be closed on a certain day or on certain days in the week. The *onus* of compliance is with the cultivators and a punitive fine is leviable in the event of a disregard of the notice.

The defects inherent in this intermittent closure of outlets for the purpose of rectification of distribution are worth enumerating.

Firstly, as even with a rough system of outlets defective distribution is not felt except at certain stages of husbandry, the process of rectification is only applicable after the effects of the incorrect distribution have been felt. It is always late in its incidence; the defect has to be complained of, the complaints verified, the distribution has to be analysed and the proposals sanctioned by a responsible officer. As these closures have considerable financial values they cannot be lightly imposed.

Secondly, whatever precautions are taken, accuracy is not obtainable, except in a rough sort of way and appeals against decision have to be dealt with.

Thirdly, the closures are extremely unpopular (as may be understood) with the cultivators dependent on the outlets which are closed. On the watercourse, the water is distributed according to a time table and this *dies non* suddenly introduced into the time table causes some dislocation in the working. The

greatest hardship occurs when closure of outlets is imposed simultaneously with the intermittent flow of distributaries, a not infrequent combination, as would occur in times of great demand for water.

Fourthly, there is waste, from improperly closed outlets or watercourses ; there is the effect of the disregard of the notices to contend with, the imposition of the fines and other disagreeable incidents ; all traceable ultimately to the outlet which is not doing the work as is required of it. It is the trouble met with in these attempts at correcting the distribution of water which has goaded the Engineers to the construction of an outlet which will, in the first instance, do the work correctly. Considering the great necessity for a good outlet, the development of the outlet has been slow.

This can be traced to the absence of an equipped experimental station and to the fact that as outlets are of great importance, the Engineer finds that the type of outlet is fixed by administrative authority and that generally within his purview, they will usually be one type only.

Employment in different parts of the Province would give, after many years, experience in different types of outlets. The experiments made have been scattered and spasmodic and sometimes without a mature comprehension of the objects required.

TYPES OF OUTLETS.

Interest will be added to the description of these types if the outlets are taken chronologically.

The open cut in the bank, roughly protected with branches of trees, the wooden pipe rectangular in section, and the earthenware pipe circular in section are the primitive forms of outlet.

The open cuts if not too closely placed to each other are not disadvantageous on inundation canals where but little control is required.

There is one canal, the Bilochanwah in the district of Multan where the cuts are not as far as two chains apart.

Open cuts acting as overflow weirs were found to be a very useful form of outlet on another inundation canal.

The pipes whether of wood or earthenware are laid in the bank at or near the level of the bed of the supply channel and act as a simple culvert through the bank.

Wooden pipes are not permanent enough.

As for purposes of administration, it is desirable to fix both the size and the position of the outlet, the earliest type chosen was the earthenware pipe, circular in section, having the ends protruding from the bank protected by small walls in brick masonry which served as revetments.

This served to protect the bank from collapse at the site of the outlet, which is a much frequented place. The cultivators sometimes have to close the orifice or to clean out the pipe in the event of choking.

The administration have also a permanent interest in having the site of the outlet as strong at least as the rest of the bank; otherwise the cultivators would be tempted to cause a failure of the bank at the site of the outlet at times of scarcity.

Such a failure of the bank allowing the water in the distributary to fill the watercourse from the particular outlet for a sufficient time to irrigate a very large acreage, would be of great monetary value to those who could profit from the accident, and it must be the object of the administration to have a bank safe from such accidents.

PIPE OUTLET AS UNIT.

The pipe outlet gave a unit to the system of outlets which prevails on certain canals.

The original earthernware pipe must have been nearly 5″ in diameter or had an area of 18 square inches or 1/8 of one square foot. This was known as one pipe. The unit persisted when the rectangular masonry barrel was used.

The other sizes are as follows :—

1 pipe	2	3	4	5	6	7	8 pipes.
Area in square feet.							
125	·25	·375	·5	·625	·75	·875	1·0

The next development was the construction of a brick masonry barrel through the bank; it was rectangular in section and roofed with brick or stone. The section of the barrel was sometimes uniform throughout and sometimes variable.

The few feet nearest to the source of supply would be of the control section and the remainder a culvert of larger section. A variation on this placed the control section at the downstream end of the barrel, a small tank intervening between the culvert of wide section and the controlling orifice.

Various reasons governed these different designs. Inability to arrive at the correct size of outlet was the reason which caused the barrel of varying section to be used. Until it was found that the cultivator was too interested in the disruption of the short control length for that length to have any life.

The barrel of non-uniform cross section is also too obvious an indication to the cultivators of the difficulty felt in deciding on the size of the outlet and a practical admission of readiness to make changes.

This gives rise to unceasing intrigue among the shareholders of the outlet, for be it understood that any outlet represents a sort of compromise between the supplier of the water and the cultivators who are shareholders on the outlet. There is often considerable change before the area to be served by any particular outlet is definitely fixed and it is desirable that the area be fixed with science and common sense rather than that the decision be liable to the influence of inter-village animosities and the varying whims of successive officers.

Then came the barrel uniform through its length. And because the labourers constructing these culverts might be cajoled into errors of an inch or so on the wide side, cast iron mouthpieces were supplied of standard sizes from ½ a pipe to 12 pipes.

Apart from the difficulty of arriving at the size of an outlet owing to the variation of hydraulic levels, there is also the variation in the areas to be served by the outlets.

These changes in the area are due to a multiplicity of causes, and in the early history of the canals were very numerous.

In order to stabilize conditions control over the outlets has eventually been vested in the administrative officer of the canals. Changes are not now made without careful consideration of the pros and cons and an improvement is noticeable.

Also, should be mentioned, the changes in the position of the outlets which interested parties among the cultivators persistently attempted.

Obviously, the nearness of the outlet to a farm was advantageous. But the correct position of the outlet with reference to the land served depends on the undulations of the surface of the country.

STEEL PIPES OCCASIONALLY USED.

Before the policy of making for stable conditions was definitely adopted, the changes in site of outlets brought in the use of the steel pipe, fixed with its end in small masonry walls, or simply laid in the bank. The idea was that they could be shifted from place to place at small expense.

These pipes were never very largely used. Their expense (accentuated by the war) was a drawback and although they are useful during the early years of a canal, they are not indispensable.

The following paragraph taken from the Administration Report of the Upper Bari Doab Canal for the year 1913-14 indicates the use to which the steel pipe was put and the difficulties encountered by the administration with the ordinary brick outlet.

" A large number of steel pipes have advantageously been substituted for masonry outlets. The trouble resulting from damaged outlets has been reduced thereby."

FIXING THE SIZE OF THE OUTLET.

The dimensions of the simple culvert outlet are usually calculated as follows :—

The discharge from measured dimensions is usually taken as $5A\sqrt{h}$, where A is the area of the outlet and h the working head. The number 5 is a product of a co-efficient into the $\sqrt{2g}$.

The expression for the discharge is the same as that for an orifice and no account is taken of the length of the barrel which may vary from 10 feet in length to about 50 feet. Great accuracy in the determination of these discharges has not been found necessary and no delicate tests have been made.

For a more accurate distribution of the water other types of outlets are being used. In all the older types of outlets the errors became merged into the approximation with which the size of the outlet was fixed.

SILTING WATER COURSES.

Before passing on to the other types of outlets, a prominent defect of the old type should be mentioned. This is the deposit of silt in the water course.

This defect the outlet shares with the heads that used to be constructed for distributaries.

The water passed into the canals of the Punjab usually contains in suspension as much sand and clay as the velocity of travel will permit and the slightest check causes a deposit of the suspended matter.

Frequently the water passing through the outlet with a velocity of three feet or more per second would deliver the water in a pool where the velocity would be reduced. This caused a deposit of the sand in suspension and the watercourses throughout the Punjab have high mounds of silt accumulated on their banks, for a distance of a quarter mile or so from the outlet.

IMPROVED OUTLETS.

In the distribution of water for irrigation, we must contemplate a distributary channel in which the supply level is constant, but watercourses in which the supply level is variable.

The outlets which have been devised to deliver a constant volume of water when the level on the supply side is fixed and the level on the receipt side varies are : The Gibb's Module, the Kennedy Gauge outlet and the broad crested weir with various shapes of approaches and of varied application.

In each of these types, there is, reasonably enough, a minimum head required to pass the " constant volume."

GIBB'S MODULE.

This type was constructed and patented by Mr. A. S. Gibb.

Mr. Gibb noticed that the surface of water flowing, in a vortex had a higher level on the outer than on the inner edge of the vortex and proposed by interference with the outer edge of the vortex partly to destroy the increased head which might tend to form, and in this manner to modulate the flow.

He designed a semi-annular shaped passage fitted with partitions and through this the water passed as through an outlet barrel.

The module was designed to deliver water to the watercourse independently of the level of the water in the watercourse which gets lower when vigorous silt clearance is undertaken by the cultivators.

Thus at times of keen demand, the attempt of the cultivators in the upper reaches of a distributary to overdraw water to the

METHOD OF FIXING KENNEDYS GAUGE OUTLET

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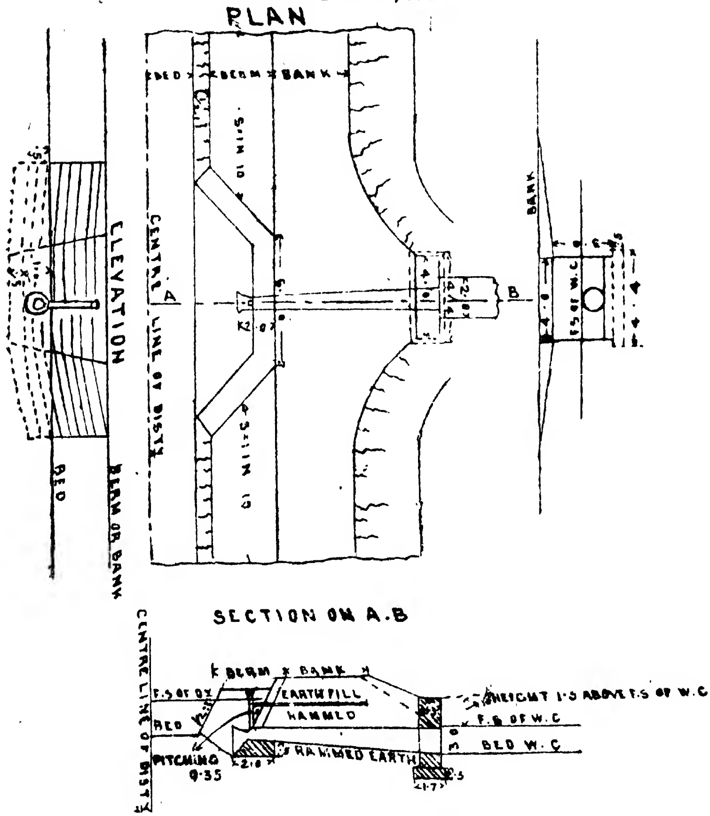

detriment of other outlets, is frustrated and there is better distribution of water and better results, or an increase of area irrigated.

A distributary of the Upper Gugera Branch, the Shahkot distributary, was provided with modules and the following table shows the effect of the installation of the modules :—

Outlet.	Rabi Permissible.	Previous to the introduction of Modules. Average of Rabi Irrigation over years.	Since introduction Rabi 1909-10.
Tail of Shahkot Disty.		1906-07, 1907-08, 1908-09.	
R ..	847	471	918
L ..	300 } 1884	246 } 1313	390 } 2375
Front ..	737	596	1067
Tail of Pacca Dalla :			
R ..	237	269	384
L ..	126 } 758	122 } 951	188 } 1182
F ..	395	560	610
Tail Panduan Minor			
R ..	324 } 751	352 } 787	523 } 1183
L ..	427	435	660
	3393	3051	4740

The module was used here and there experimentally but has not been considered suitable for universal application.

THE KENNEDY GAUGE OUTLET.

This outlet, patented by Mr. R. G. Kennedy, depends for its action on the constant discharge of an orifice which discharges into air under a constant head of water.

By admitting air to the jet, the effect of discharge into air is obtained.

The outlet was patented about the year 1909 and has been found in the Punjab to be sufficiently accurate to solve the problem of the distribution of water on the channels where it has been tried.

It requires a minimum working head of one quarter of the depression of the orifice and as a depth of 2·5 is very common among distributaries, the corresponding head required is 0·6.

The outlet, as marketed, consists of the following parts :—

(*a*) A bell-mouthed opening tapering to the orifice proper which is made to a gauge.

(*b*) The air vent which is bolted to a seating on the first part.

(*c*) A delivery pipe tapering in shape ; this is bolted to a collar on *a*.

(*d*) A stay rod fixed to the top of the vent pipe and anchored to the earthen bank or in later patterns an angle strut.

On its appearance the Kennedy Gauge Outlet received a better welcome in the Punjab than the Gibb's Module.

Officers were detailed to experiment with it and the results of their experiments were published.

By 1914 the outlet had achieved some popularity and was being used in increasing numbers.

The method of fixation was various.

For the sake of cheapness, the outlet is supplied with a delivery pipe too short for any distributary bank. Sometimes the outlet was just placed in a trench in the earthen bank and the trench was refilled. In some divisions, however, they were built up and around with brickwork and expanded metal.

Even when on trial, the Kennedy Gauge Outlet, or any form of pipe outlet should be so fixed as to make it secure and not liable to damage or interference. This can be done without the necessity of building up the outlet in masonry.

The popularity of the Kennedy Gauge Outlet with the Engineers is attributable perhaps to its mobility and to its relative cheapness.

VENTURI - SHAPED

FLUME OUTLET

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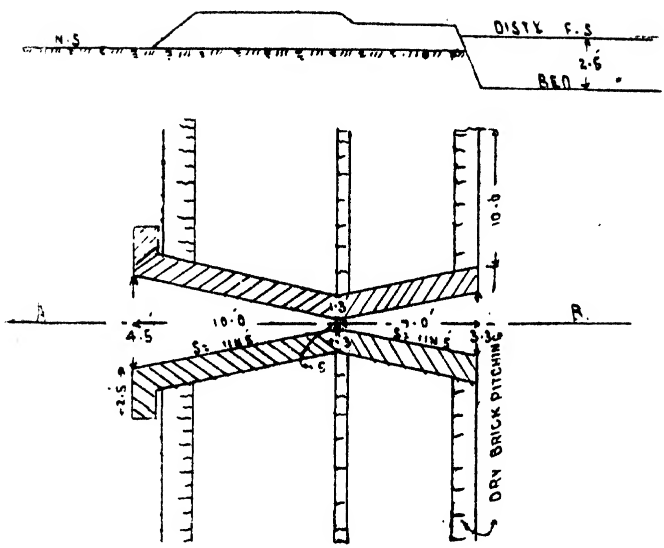
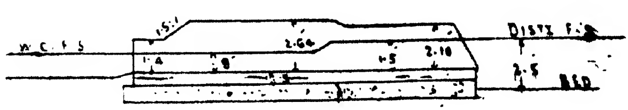


SECTION ON A.B.



The first patterns made sacrificed a good deal of efficiency to cheapness and in parts this defect has been removed in the latest model.

The Kennedy Gauge Outlet is one of the most useful contrivances for the distribution of water for irrigation to meet the requirements of distributaries in the Punjab, in spite of the fact that its maximum efficiency is slightly diminished by the action of the cultivators in plugging up with clay the visible air vents.

THE BROAD CRESTED WEIR WITH SPLAYED APPROACHES.

The broad crested weir with splayed approaches does not seem to have received attention, except lately, as an instrument for the measurement of quantities of water.

This may easily be due to the circumstance that the co-efficient applicable to the theoretical formula is a variable one.

On one irrigation system, however, if the type of weir were standardized, a co-efficient would be adopted giving the required accuracy in computation.

The broad crested weir has the property that the discharge over the weir does not increase when the water level downstream falls after the maximum head required to govern the discharge (namely, one third of the total depth on the crest) has been attained.

A simple form of broad crested weir, used generally as a weir with a free fall, was the first type to be used.

The type appears to have been adopted in the Punjab about the same time as the Gibb's module, and it was used at the tails of distributing channels where the supply is delivered simultaneously to two or three and occasionally four field supply channels or watercourses as they are termed.

In the first instance the weir was used in conjunction with an orifice, the weir supplemented the discharge through the orifice when a flush came down the distributary. Later the orifice was omitted.

Some form of weir is particularly desirable at this end of a distributing channel on account of the varying levels of the land served and on account of the competition that exists for the water reaching the tail, especially so, as has been noticed, on channels where incorrectly sized outlets would cause a deficiency of water at the tail.

In the absence of a weir, the levels of the watercourses would be lowered till one of the outlets (assuming the simple orifice type) discharged with a free fall.

If the level of the fields precluded such an advantage from any of the other watercourses, that one would be placed at a disadvantage.

The broad crested weir as first utilized for a cluster of outlets at the tail of a channel or " tail cluster " was of different construction to that adopted for individual outlets at a later period.

TO CALCULATE THE SIZE REQUIRED.

The expression obtained by analysis for the discharge over a broad crested weir of infinite length is $3{\cdot}09\, h^{3/2}\, l$ (Unwin's Hydraulics, page 103) and the discharge will be invariable so long as the working head is greater than $\frac{1}{3}\, h$.

Converging approaches and diverging wings increase the discharge by nearly 10 per cent. and the expression $Q = 3{\cdot}33\, h^{3/2}\, l$ has been applied in practice, and found accurate.

In plan such a weir can be described as a venturi shaped flume, as for the discharges passed and the depths worked with the throat is comparatively narrow.

Delicate tests of the value of the co-efficient adopted have not been made and there is no necessity to be dogmatic regarding the acceptance of one co-efficient in preference to another until a flume of a definite shape is adopted and the co-efficient is determined by accurate experiment.

Previous to the adoption of 3·33 as the co-efficient applicable 3·7 was used, until more frequent tests showed the value 3·33 to be more accurate.

In spite of these early approximations, these weirs were used to rectify errors in distribution, greater than 10 per cent. and they showed their worth even when they were imperfectly calibrated.

They were used on inundation canals in order to improve the distribution of water through outlets larger than are met with on perennial systems.

AN INTERMEDIATE DESIGN.

An intermediate design consisted of an outlet which was a combination of a pipe under the bank and a weir, but the outlet did not progress beyond the experimental stage.

The weir is admittedly a useful instrument for the distribution and measurement of water and the introduction of the less useful pipe (except as a culvert under the bank) does not appear to be a helpful innovation.

The type may, however, be considered as a stage in the development of the outlet. The first outlets were pipes and in order to rectify the defects inherent in the pipe outlet, the weir was introduced.

Eventually the pipe disappeared and the weir remained.

A RECENT DESIGN.

More recently a type of outlet has been proposed which will distribute the water proportionately as does a weir, and which will be also adjustable.

As the weir is not conveniently adjustable by raising the crest or narrowing the weir which would involve rebuilding at least one of the sides, he proposes a roof block which it is possible to dismantle and replace at small cost.

This type is now being tried.

The remarks made with regard to the adjustability of some earlier types of outlets must hold with regard to these also.

The adjustable outlet may be a necessity on a canal which is in process of development, but when development has been reached, the outlet should be a permanent feature.

FIXING AN OUTLET IN THE EARTHEN BANK.

The earliest outlets were simply placed in a trench in the bank and the trench was refilled. If the bank material had settled down, the refill was always weaker and the erosive action of the water weakened the bank at the site of the outlet.

The site of the outlet should be not less strong than any other part of the bank and there are reasons why it should be even stronger. The bank is subject to more traffic at the site of the outlet than elsewhere.

If the bank at the site of the outlet is weak, there is, to unscrupulous cultivators, the temptation to effect a breach or in some way to tamper with the outlet in periods when water becomes very valuable. It is at such times that an able administration should ensure the accurate distribution of this valuable commodity.

The site of the outlet is not the place where cheapness of construction is to be indulged in without discrimination. If the water is of any value, it deserves to be led through the bank in a form of outlet which will be of as sound construction as can be undertaken.

The first permanent form of outlet consisted of earthenware pipes laid on a concrete slab, the ends of the pipe as they protruded from the earthen bank were finished by being built into two short revetment walls, the length of which was usually 3·0 feet. These revetment walls especially in a deep channel never formed with the bank a homogeneous or a well finished piece of work.

An improvement was sought in building the revetment wall to a batter similar to that the sides of the channel and had the revetment walls been made long enough a much needed improvement would have been achieved ; but restricted expenditure checked improvement.

Instead of a sloping wall, a revetment of dry brick laid as pitching on the inner slope of the bank and resting on a foundation of brickwork or concrete, if of sufficient length, would give as finished an appearance as the materials available permit ; the appearance would be sufficiently pleasing and there would be sufficient protection to the bank. Experience has shown that a length of revetment not less than twenty feet, generally, is required to uphold the bank and to secure that a sound job is made of the outlet site. Attempts to cheapen construction and to restrict the length to ten feet show a poor result, requiring frequent attention in repair.

The outlet figures largely in the daily work of administration and rules and regulations describing procedure in connection therewith are to be found in the Canal Act and in the Manual of Orders.

THE WATERCOURSES.

At the outlet, the water is delivered to the cultivators (the clients), and it passes practically out of the control of the supplying party. But not out of absolute control as certain rules exist as to its use. A few will be enumerated. The water is to be divided according to the area of the fields or farms served.

The water must not be wasted.

The water must not be used in an unauthorized manner.

For breaches of the rules, penalties are leviable.

The watercourse usually serves one village, a part of one village or parts of two villages.

All the farmers, tenants, or cultivators on the watercourse become shareholders in it in proportion to their cultivated holding.

Should the shareholders disagree about the distribution, a time table is drawn up by the officer incharge of the distribution and after certain formalities this time table has the force of law and a shareholder is liable to prosecution by the aggrieved shareholder for infringement of it.

On most canals, the alignment of the watercourses is sanctioned by the administration and any changes have to receive administrative sanction.

CHAPTER IV.

Irrigation from Wells.—Lift Irrigation.—Inundation Canals.

IRRIGATION ALONG RIVER BANKS, BY FLOW AND LIFT.

Individuals and communities whose lands lie along natural courses of water divert the stream on to their fields when the water is needed and the diversion is feasible.

The practice is common and the following cases may be mentioned in illustration.

In the foot hills of the Himalayas, where terraces can be made along the hill side, these terraces are cultivated and irrigated from the springs and rivulets which flow down the ravines.

In the Swat River Valley, large watercourses are constructed leading from the river to irrigate terraces of rice cultivation.

Where such water rights had been established around the headworks of the Upper Swat River Canal, some ingenuity was needed when aligning the canal to maintain the established interests.

In the Punjab plains riparian owners can occasionally take advantage of direct irrigation from the river.

Such direct irrigation by overflow is only possible in floods and the crop raised is usually some coarse kind of fodder.

On the land which has been subjected to river flood wheat is grown in the winter.

Along the banks of rivers and river creeks the land above the flood level is irrigated by lifts throughout the year.

A bullock driven Persian wheel is the common form of lift employed.

IRRIGATION FROM WELLS.

At some distance from the river bank, the cultivator has to dig a well to get down to water level and on this well the lift is placed. The well is often unlined if it is shallow, but such a well is liable to collapse.

Farther away from the river, the wells are deeper and have to be brick-lined.

Throughout the Punjab, the lift employed is the bullock-driven Persian wheel, as the bullock is there the most economical draught animal.

The discharge obtainable from a well 10′ to 15′ deep is about 0·1 cusec and this is often greater than the rate of infiltration to the well, so that the height through which the water is lifted increases as the well is worked and besides, the well requires periods of rest to refill.

When lifting water from a river creek, or from wells close to the river this is not felt. The river creek may, however, completely dry up in the winter.

As the distance from a river increases the level of the land is higher and normally the level of the spring water or subsoil water gets lower. The depth of a well increases.

It is recorded that wells up to a 100′ in depth have been used to irrigate, but the area which can be irrigated from a well of this depth is very small.

In the greater parts of the Punjab such lands are now served by perennial canals.

Irrigation from wells is done largely to supplement during the winter that from inundation canals in the riverain tracts, or in such localities close to the river where no canals have been dug.

TUBE WELLS.

Ordinary brick lined wells are often intermittent, that is, the in-flow is not as fast as the rate at which water can be pumped out. The well does not tap a sufficient area of ground water.

A more expensive well known as a tube well, can be constructed to tap a deep water bearing stratum and to yield a continuous supply much greater than the yield from an open well.

In localities not supplied with canal water a tube well fitted with a power driven pump can generally be economically installed.

That is to say, the capital spent in construction would be more than repaid by the increased outturn which the water would ensure, taking into account the costs of operation.

In a watercourse, water can be led half a mile without a serious loss by absorption in transit. A tube well placed in the centre of a square mile would command an area of 640 acres and would need to discharge one cusec in the Punjab for successful cultivation ; this would enable 500 acres to be cultivated during a year. Tube wells suitable for use in the Punjab are purchasable, ready for erection.

With the ordinary well about 10′ to 15′ deep a pair of bullocks can mature twenty acres in the year, that is, 7 acres in the Kharif and 13 acres in the Rabi.

A well is often shared by several adjacent farmers who take it in turns to irrigate. The limit of area which can be thus protected by a well must be taken as the area irrigable in one day multiplied by the number of days between two essential waterings in the driest weather.

LIFT IRRIGATION.

Water from canals is lifted on to parts of the country uncommanded by flow either by Persian wheels or by steam driven pumps or by pumps driven by electric motors supplied with power from a central plant.

The Persian wheel is different in detail to that used on a well ; instead of a rope chain on which are strung small earthen vessels, large earthenware pots or 4 gallons tins are fixed direct to the vertical wheel of the gear and the water is lifted through the diameter of the wheel and dropped into a trough just above the centre. The discharge is probably as high as 0·3 cusec.

Lift irrigation on a large scale has been developed in the Punjab near Buchiana on the Upper Gugera Branch and at Renala on the Lower Bari Doab Canal.

At the former place steam engines drive pumps for local pumping and drive dynamos for the supply of power to pumps at a distance from the central station.

At Renala there has been erected a powerful hydro-electric generating station where the supply in the canal will generate power which will be transmitted to substations over an area supplied by a distributary from which the water will be lifted to the otherwise uncommanded lands.

There are several small lift schemes, the power for which is derived from a small portable engine (now fixed for the purpose) which drives a centrifugal pump and delivers on an average 2 cusecs.

INUNDATION CANALS.

POSSIBILITY OF INUNDATION CANALS.

In the Punjab comparatively few riparian owners can take advantage of the high flood level to irrigate their land by overflow, and such waterings would be irregular and infrequent.

If, however, advantage is taken of the fact that the slope of the rivers is steeper than the general slope of the country in the seaward direction, canals, with a gradient flatter than that of the river can be constructed in which, at some distance from the offtake in the river bank, the water level will be higher than the level of the adjacent fields, and consequently irrigation by flow is possible.

The period during which irrigation from these canals is practicable extends usually from the middle of May to the 1st week in September.

ORIGIN OF INUNDATION CANALS.

Canals constructed in this manner, without any obstruction of the main river, are called Inundation Canals.

Their sphere of action lies between the riverain and the " bar " as the high watershed between two rivers is termed.

As a class their origin is remote.

Remains of old alignments can be traced in those parts of the country where river beds have once been.

The present inundation canals are, however, not much more than two hundred years old and a few are of more recent date.

In the Punjab, inundation canals have their greatest importance in the Multan, Muzaffargarh and Dera Ghazi Khan Districts and there are also the Shahpur Inundation canals in the Shahpur District.

The canals in the three districts first mentioned were, generally constructed under the Pathan rule which preceded the Sikh government in that part of the Province.

A Sikh Governor of Multan, Sawan Mal, had jurisdiction over the whole district and became notable for his liberality in encouraging the excavation of canals and for the wisdom of the canal administration during his governorship.

The canals take off the Chenab, the Indus and the Sutlej rivers. The canals from the Chenab usually take off from the main stream and those from the Indus take off side channels of the river.

CANAL ADMINISTRATION PREVIOUS TO ANNEXATION.

Previous to the annexation, the annual clearance of the canals and repairs were borne by the community forced thereto by the active interference of the administration. Each village or proprietor was forced to supply labour in proportion to the extent of their interests in the canal, and the collection of the labour and the clearance and repairs of the canals were supervised by the district officials.

When the work was unusually heavy the irrigating cultivators subscribed cash for hired labour, the amounts of the subscription being in proportion to the benefit derived by each cultivator from the canal.

The canal administration was closely supervised by the former governments and was specially effective under Diwan Sawan Mal.

The forced labour furnished were called *chers* and the system was known as the *cher* system.

CANAL ADMINISTRATION SUBSEQUENT TO ANNEXATION.

Subsequent to annexation, the administration of the inundation canals devolved on the civil officers of the district. The old system of active interference was withdrawn and the canals left to get on as best they could.

A different system of administration with different officials was evolved, but lacking the close supervision of the previous system the canals steadily deteriorated until they were brought under the jurisdiction of the Public Works Department in the year 1880.

Gradually the *cher* system has been abolished and the substitution of a water rate or cash assessment introduced.

Hindered by the conservative policy of the *cher* system the inundation canals have developed slowly.

But of recent years they have benefited by the application of scientific methods to the distribution of water. Water is now made to go farther, and the poor man has now a better chance of getting his share.

There is considerably less waste.

The general improvement effected on the inundation canals has been primarily the collection of several of the canals into one large canal having one intake in the river bank.

This has greatly simplified the annual clearances and ensured better supplies in the branches when a low river makes it incumbent to run the branches in rotation.

The next important improvement is the introduction of a scientific outlet system to replace the innumerable cuts ; the substitution of a single watercourse with a time share basis of distribution for the several competitive watercourses which were sometimes miles in length and which endeavoured to compete with each other by the vigour of their silt clearances.

THE SHAHPUR INUNDATION CANALS.

In the Shahpur District, the canals excavated have been mostly so dug through the incentive of the district officers since the year 1864.

The first canals excavated showed themselves to be so remunerative that large land owners were quick to seize on this advantageous method of adding to their wealth.

Eventually the canals were purchased by the irrigation branch. The smaller canals were, as much as possible, amalgamated and they now form the Shahpur Imperial Inundation Canals.

There are still in this district several private canals. These canals all but one take off the left bank of the Jhelum river.

ANNUAL SILT CLEARANCE OF INUNDATION CANALS.

The reach of an inundation canal adjacent to the river, that is, the offtake or head reach has to be silt cleared every year. By silt clearance a full discharge is obtained for the canal before the river attains its maximum flood level.

During the falling river at the end of the flood season, the canal offtake becomes comparable to a back water and the stilling effect causes deposit of the silt which has to be cleared before the following season.

Inundation canals are provided with escapes at a short distance below the intake to enable the high supplies due to floods to be passed safely back to the river.

Whenever possible a subsidiary head reach or intake is excavated and kept in reserve in case the principal one should be either accidentally silted or otherwise rendered unfit by river erosion.

THE GREAT VALUE OF THE EARLY AND LATE SUPPLIES.

During the opening days of an inundation canal, and also during the last days of its flow, the water acquires a very high value and the distribution is a difficult matter.

It will be readily understood that copious water in the middle of a crop is valueless unless the sowings are extensive and the early supplies determine the area of the sowings.

With a belated supply nothing more valuable than grass can be raised.

The late supplies are valued for their influence on the maturing of the crop and also a copious supply late in the Kharif season enables tillage for the ensuing wheat or rapeseed crop in the Rabi.

ASSOCIATION BETWEEN INUNDATION CANALS AND WELLS.

The area protected by inundation canals also needs the supplementary protection of wells. Some valuable Kharif crops, such as sugarcane, need more water even after the closure of the inundation canals and these crops are matured with the assistance of irrigation from wells.

In a similar manner the watering of wheat and rapeseed after a preliminary watering from an inundation canal, is dependent on irrigation from wells.

CHAPTER V.

ABSORPTION LOSSES, LINING OF CANALS, WATER-LOGGING, DRAINAGE.

The canals of the Punjab are excavated out of soil and the banks are built up with soil. The soil is porous and absorbent and part of the water entering the canals from the river is lost by absorption before it reaches the fields.

On the average canal in the Punjab, the loss between canal head and field is estimated at 50 per cent. and the loss is distributed as follows :—

in Main Canal	..	20%
in Distributaries	..	6%
in Watercourses	..	24%

The determination of the value of the loss by absorption in canals has exercised the Engineers in the Punjab since the earliest times.

One of the earliest experiments of which there is a record is that carried out in a reach of the Talwandi Distributary in the Ludhiana Division of the Sirhind Canal. The reach was about two miles long, with a free fall at each end. At these falls orifices in iron plates were fixed, and the discharge at each end of the reach calculated from the measured head on the orifices. As the result of the experiment, the losses were calculated to be 5½ cusecs per million square feet of wetted perimeter, for that size of channel, in which the depth was about 2·5 feet.

The general rule at that period was to take the loss in a distributary as 10 per cent. of the discharge entering, and in canals of greater depth the loss was taken as 8 cusecs per million square feet of wetted perimeter.

Earlier, in 1896, experiments had been carried out on watercourses over lengths extending from half a mile to two miles, and with discharges varying between 1·0 cusecs and 1·4 cusecs.

The results obtained showed that the absorption varied as the nature of the soil in which the watercourse was excavated. The results showed losses varying from 10 per cent. to 50 per cent. per 5,000 feet (canal mile) length of watercourse.

It was estimated that in an ordinary village watercourse, the loss per mile could be taken as 20 per cent. of the volume entering the watercourse.

The object of the experiments was to determine whether it was economical to save water otherwise lost in absorption, for utilization in extensions of the canal system.

The water saved in the canals, branches and distributaries would be so utilizable. The water saved in the watercourses would admit a larger area to irrigation from each watercourse.

In 1901 the position with regard to waterproofing of canals and saving of water lost in absorption was this. Excepting the Western Jumna and Sirhind Canals, there was enough water in the rivers to make up for the loss by absorption in the canals, and as far as the watercourses were concerned, it was not found practicable to waterproof them ; as any waterproofing work would have to be done by Government agency and unless the watercourse was maintained very carefully, the waterproof lining would rapidly deteriorate. Such maintenance was beyond the scope of the cultivator. Lining of watercourses was therefore not economical.

On the Sirhind and the Western Jumna Canals, it would have been possible to utilize the water saved from absorption for extensions of the system. But the cost of lining canals as then estimated was much in excess of any revenue that might be obtained from the water saved.

The literature of the time indicates that the lining of the distributaries and minor distributaries was the principle objective.

The larger and deeper channels are, however, those from which the loss from absorption is greatest. They also flow for a greater number of days in the year.

There does not appear to have been an early recognition of the fact that the loss from a deep channel by absorption is greater than the loss from a shallow one. Uniform rates of absorption were used in calculations. Latterly the dependence of the loss by absorption on the depth of water in the channel has been recognized, and given effect to in the formula:

$Q = CAD$.

Q = Absorption in cusecs.

C = A co-efficient varying inversely with the hydraulic mean depth.

A = Area in millions of square feet of reduced wetted surface of the channel, *i. e.*, of the bed of the channel plus half its side slopes.

D = Depth of water in feet.

Although calculations showed that it was not financially remunerative to save, by lining of canals, water that would otherwise be lost by absorption, another consideration, namely, the re-appearance of the lost water caused Engineers in the Irrigation Branch to incur considerable expenditure in attempts to render waterproof the beds of main canals and to reduce the loss by absorption.

Much of the water which year after year percolated from the canals is stored in the ground and serves to raise the level of the ground water or subsoil water. This was being noticed yearly from the measurements of the water surface levels in wells, recorded throughout the irrigated tracts.

But it was not till the year 1908 that the results were forced on the notice of the Engineers, especially on the Lower Chenab Canal. In that year there was very heavy rainfall as will be apparent from the table below.

Year.	1899-1900	1900-01	1901-02	1902-03	1903-04	1904-05	1905-06	1906-07	1907-08	1908-09	1909-10	1910-11
Rainfall monsoon months ..	2·0	6·3	4·4	5·5	8·2	2·6	7·0	8·0	4·4	22·1	9·4	8·3
Rainfall whole year ..	3·9	8·8	6·9	9·0	13·6	6·1	11·5	11·4	8·9	24·3	14·6	15·4

Year.	1911-12	1912-13	1913-14	1914-15	1915-16	1916-17	1917-18	1918-19	1919-20	1920-21	1921-22	1922-23
Rainfall monsoon months ..	1·9	5·8	9·5	12·5	1·5	12·1	21·3	4·5				
Rainfall whole year ..	4·8	9·7	14·0	18·8	3·3	14·0	27·6	8·0				

The effect of this rainfall and of the flooded river was the swamping of certain low-lying areas, close to the river, in the paths of the natural drainages. It was observed also that an increasing number of villages which previously used water from the canal for irrigation required less and less of it.

An outcry was raised, in the first instance by the Civil and Revenue Officers of the district and the Irrigation Branch of the Public Works Department was called upon to institute remedies against the waterlogging which was attributed to the canals.

The Engineers rightly accepted the task of relieving of its excess water the land declared to be waterlogged. The rise in spring level, the decrease in area irrigated and the increase in area waterlogged or deteriorated were examined in detail.

The rise in subsoil water level is fairly uniform and on the average amounts to 1·0 foot (app.) per year, the maximum rise recorded being about 2·0 per year. The rise of the water level in the soil practically ceases when the water level reaches 5′ to 10′ from the surface, for it is then able to drain away to the river. It is on areas where the water level is close to the surface that the effect of heavy rainfall such as that of 1908 is felt.

The following remarks are reproduced from the annual report for the year 1915 :—

Experience gained during the last few years shows that any canal project which excludes from its scope the improvement and upkeep of the entire drainage system within and on the outskirts and its irrigation limits is deficient in one of its most essential aspects.

The production of crops year in and year out on a limited area unskillfully and unscientifically treated can only be achieved by copious watering at the risk of ultimate exhaustion and severe damage from over saturation and waterlogging.

HISTORY OF WATERLOGGING ON THE LOWER CHENAB CANAL.

On the Lower Chenab Canal there were two tracts in which waterlogging was declared to be serious.

One of these was an area lying close to the left bank of the Chenab river in a locality where the river valley is the narrowest. It lies parallel to the Jhang branch (miles 27 to 32) which is here about two miles distant from the river.

During the monsoon of 1908, heavy rainfall and a high river contributed to swamp this tract which is naturally ill-drained. The waterlogging of the soil was, however, attributed to the canal.

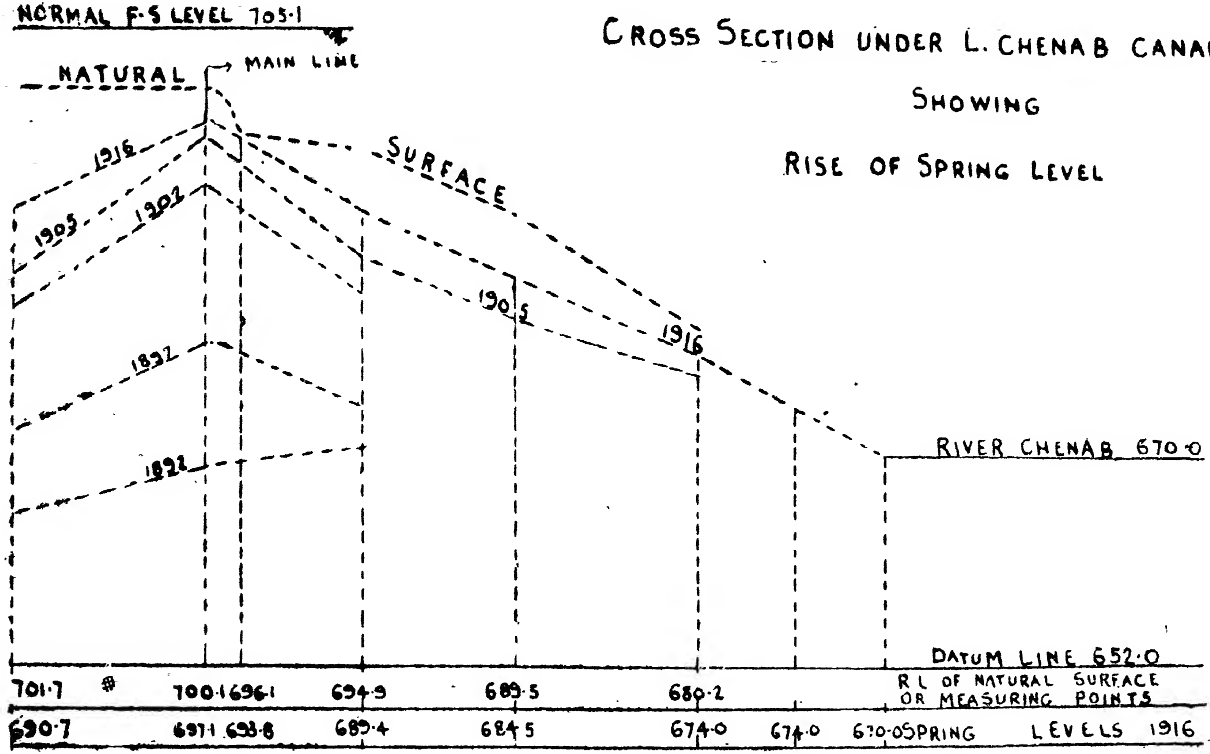
The other tract is that lying along the drainage lines tributary to the river, which cross the main canal between the 19th and the 28th miles.

In pre-canal days the land lying on the banks of these drainages was more intensely cultivated than land elsewhere as there was more moisture available, and there is no record of the

CROSS SECTION UNDER L. CHENAB CANAL (MAIN L.)

SHOWING

RISE OF SPRING LEVEL



heaviest rainfall causing land to go out of cultivation. Years of heavy rainfall were probably years of increased cultivation the ground being nowhere waterlogged. There were lifts fixed in these drains for irrigation of the land ; the drains were blocked by means of earthen banks to cause water to rise as high as possible. At other places watercourse crossings or rough bridges interfered with the waterway. As drains these tributary channels had lost their value.

The Lower Chenab Canal was opened in 1892. In 1908 the subsoil water level had risen to within 10 feet of the surface in the path of these drains ; the heavy rainfall of that year collected in the drain area, was not able to soak into the already wet soil, was not needed for irrigation, and it found that the outlet to the main river was blocked ; that is the bunds and other obstructions in the drains, kept up the water which could not pass off to the river.

Certain areas remained wet until past the time for wheat cultivation and even throughout the following winter.

The two following years were years of exceptionally good rainfall, and served to accentuate the effects of the monsoon of 1908.

APPEARANCE OF ALKALI.

Another result of the proximity of spring level to surface in some of these areas is to cause the formation of alkali salts on the surface through the more intense weathering which the humid condition makes possible. The slope of the fields is not sufficiently steep to permit rain to dissolve and wash away the salts ; they are only washed into the top layer of soil and reappear when the water has evaporated.

THE MEASURES PROPOSED.

As a result of their deliberations on the subject, the Engineers decided to dig out the natural drainages and to line the canal bed and inner slopes with substances impermeable to water.

The excavation of the drains was an obvious measure of relief ; it would ensure the timely removal of the rain water which tends to accumulate in the drainage and so avoid the evil consequences of its stagnation. Accordingly the deepening of natural drainages was sanctioned.

The lining of the canals was advocated with much earnestness by many Engineers ; some of whom had shown by experiment

that the soil in the reach of the main Lower Chenab Canal between the 19th and the 28th mile was of exceptionally porous nature.

Theoretically, the lining of the canal strikes at the root of the trouble of waterlogging, if it is due to percolation from canals, by removing the percolation.

As a practical measure, the proposal was adopted to line a long reach, 13 miles of the main canal, and a long reach of the Jhang Branch ; it was anticipated that the work would take a long time, especially in the main canal, owing to the infrequency of closures.

At the same time, irrigation was considerably restricted, where it was not much required. Several distributaries were closed. The Beranwala reservoir at mile 28 of the Jhang Branch ceased (in 1916) to be utilized as an escape, a channel being excavated between the canal and the river to serve as a substitute.

Of the remedial works proposed and started in 1911, that comprising waterproofing of canals came to an end in 1915 or very soon after.

LINING OF CANALS WITH WATERPROOF MATERIAL.

The work on lining the canals had to be in the first instance of an experimental character. By experiment had to be determined the best medium, the method of laying and the detailed processes for the continuous execution of the work. Above all, a lining reasonable in cost had to be obtained. For the main canal, the material proposed was clay puddle, that being the most economical and durable material for that locality.

Actually only one-and-half miles of the main canal were lined and it was not found expedient to proceed any further. Clay puddle was eventually declared unsatisfactory for that locality owing to the absence of good clay sufficiently close to the canal.

On the Jhang Branch five miles of the bed, ninety-eight feet wide were lined with cement plaster. Part of the reach was lined with various mixtures and thicknesses and four-and-half miles were lined with cement and sand (1 : 5) plaster laid one-and-half inches thick.

Also the Kot Nikka Branch, a channel discharging 287 cusecs and flowing 3½ feet deep which was then considered to be contributing to the percolation was lined for six miles out of its initial reach of seven miles.

The two longest reaches lined were those of the Jhang Branch and the Kot Nikka Branch, cement and sand plaster being used.

Other shorter reaches of canal were lined on the Sirhind and Upper Bari Doab systems, the total mileage lined being twenty-eight at sixteen different places.

Apart from the Jhang and Kot Nikka linings which are between them 11 miles long, there are then 17 miles of lining at 14 places, the average length being about a mile.

The short lengths would have no effect on percolation, but would indicate the suitability of the material for application and its durability.

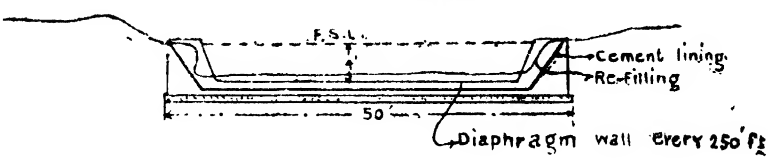
These experimental linings of the canals followed experiments on the effect of lining placed in tanks and trenches made to imitate watercourses. The materials tried in the tanks and watercourses were clay, *kankar* lime, cement slurry, cement mortar, crude oil, oil paper, tiles.

Cement mortar laid 1½ inches thick at least and clay puddle were the only media found effective.

CROSS SECTION OF BRANCH CANAL

SHOWING CEMENT LINING

SCALE 1/200



In the case of the lining carried out on the Jhang and Kot Nikka Branches, there is matter for regret, that in each case a complete reach, between two falls, bed and slopes, was not lined throughout. Complete reaches would have been valuable as the determination of the loss from percolation would have been measurable directly. The value of the lining, as it aged, would also have been ascertainable.

In the absence of the possibility of accurate measurement, the effect of the lining was determined by conjecture, whereas it was also known that the effect of the lining on percolation was also masked by the simultaneous effect of drains which had been constructed at the same time that the lining was being placed in position.

CONSTRUCTION OF DRAINS.

Previous to the decisions taken in 1911 to deepen the drains between the main line of the Lower Chenab Canal and the river, there had been some preliminary drain construction in the years 1903 to 1906.

Two drains had then been dug, one on each side of the main canal between mile 19 and the syphon at mile 25; a shallow drain was also graded along the natural drainage leading from the syphon as an outfall for the discharge from the syphon.

Although work on the lining of the main canal and the Jhang Branch were started in 1911, work on drain deepening was not started till 1913, probably when it was found that lining was impracticable. The drain dug in 1906 was shallow and did not go far enough, it transferred the stagnation from the proximity of the syphon to another depression in the natural drainage. From 1913 the objective was the river itself and the drain was eventually made to discharge into that.

The effect of the drains was very distinct. Whereas a field survey in 1914 had shown that 11,637 acres were swampy or waterlogged, the area so declared at a survey in 1917 was only 1,831 acres, the area reclaimed being nearly 10,000 acres.

PREVIOUS TROUBLES WITH WATERLOGGING.

The canals of the Punjab had even a more unfortunate experience of the formation of swamps and waterlogging and of the effects thereof when irrigation was primarily started on the Western Jumna Canal.

Alignments were selected for the initial facility they afforded. No provision was made to pass cross drainages. Swamps were formed. Collapse of banks caused damage to villages and crops. Severe epidemics of malaria visited the canal tracts. That of 1843 was so severe that Karnal was abandoned as a cantonment.

NOTES ON DRAIN CONSTRUCTION AND MAINTENANCE.

The main drains should terminate at the river and the bed level at the junction need not be more than 1·0 above low water level in the river; the slope of the drain will be the natural slope of the country through which it passes. The bed width of the drain will be such as to give it a moderate discharging capacity.

it will always overflow after rain ; it would be uneconomical to make it too wide. Opinion is divided as to whether it should be aligned along the natural drainages or whether shorter alignments to the river should not be excavated where possible. A decision in that respect will probably be different at different places and at different stages of development. In the Punjab generally, the slope will have to be flat and the drain will have to be repeatedly cleared of the soil which flows in from the sides and which collects from obstructions.

EXAMINATION OF THE PROBLEM OF WATERLOGGING.

About the year 1909, the opinion was formed on the evidence of the waterlogging visible that percolation from canals was responsible for the waterlogging ; it was also alleged that land was going out of cultivation and that the evil was a progressive one.

The first efforts were directed to lining of the canals with waterproof material.

When the impracticability of this solution became obvious recourse was had to drains.

In the year 1920 an examination of the whole problem and a sifting of the evidence bearing on the subject disclosed that—

(*a*) the waterlogging was attributable directly to excessive rainfall ;

(*b*) although percolation from canals causes a rise in spring level ;

(*c*) there is no falling off in cultivation and there is no instance of waterlogging which adequate drainage will not relieve.

Sufficient evidence has now been obtained to show that in certain ill-drained localities bordering on the rivers, years of heavy rainfall will produce swamping. These localities are low-lying and copious rainfall occurring simultaneously with a high river level make drainage out of the question.

In other tracts the high spring level makes the land liable to waterlogging in years of heavy rainfall if the drainages are ineffective ; if the drainages are graded and given an outfall in the river there is no likelihood of trouble arising.

The rise of subsoil level on account of percolation from canals is not in itself evil, provided the subsoil level does not rise so high as to cause the appearance of alkali or to make the land so damp as to be untillable.

The opinion has been expressed that the substitution of a condition in which the subsoil level is close to the surface for one in which that level is 100′ below the surface is an insurance against a possible calamity which might throw the canal out of action for a period of years.

The lining of established canals with waterproof material for the purpose of saving the water appears to be at present both an impracticable and a financially unsound scheme.

This does not imply that a new canal could not be lined with economy if a material as cement is obtainable at a rate commensurate with the value of water. Because in a new canal there will be the advantage of saving in width, which implies a smaller cost for the bridges and all the works across the canal and a grade which would save the construction of falls.

CHAPTER VI.

Registration.

AREA, THE BASIS OF SUPPLY.

The principle according to which water is distributed in the Punjab is that water is supplied to each individual or to each community in proportion to the area.

As has been mentioned in other chapters the intensity of irrigation and the water allotted per unit area varies on different canals or sometimes on different parts of a canal, but apart from these differences, equal areas are due equal volumes of water.

This is achieved by the maintenance in the field watercourses of a constant discharge (as nearly as possible) which is distributed for periods proportionate to the areas of holdings.

There is scope for individual efficiency as a cultivator who could use the water economically would be able to spread it over a greater proportion of his holding to his own advantage.

HOW THE CHARGE FOR WATER IS APPROXIMATED TO THE AMOUNT USED.

Charges are higher for crops which require more water or which remain on the ground for a longer period, and consequently receive a greater number of waterings. But the charges are not in strict accordance to the water used. The water is charged for by assessing a water-rate on each matured acre of crop.

There are various rules for the remission of the assessment when the crop does not come to maturity.

WASTE OF WATER AND MANNER OF DEALING WITH IT.

But the methods of assessment were for long conducive to waste. Waste has been decreased by a more strict limitation of the size of the outlet with the hope that that which is scarce will not be wasted.

The shareholders on a watercourse do not seem to be able to pull together and maintain the watercourse in an unleaking condition. Each shareholder is afraid to do more than his share of maintenance with results in consequence.

It is strange but common to receive woeful applications to relieve a distressful shortage of water to find on inspection that the little (!) that is being received is not being carefully utilized.

There is under the Act a penalty leviable for water wasted, but it is cumbrous of application and not deterrent.

The more reasonable way of dealing with glaring instances of waste is to check the size of the outlet in comparison with the area served and to first ensure that there is no discrepancy there.

REGISTRATION.

In order to register the areas served by the canal a staff of registrars of irrigation (patwaris) are maintained. For each village and for each crop they are supplied with a register (Shudkar-Khasrah) and in the register is entered field by field the irrigated area. Each field in a village has a number and particulars of that field, namely, the area and ownership are recorded in the village field book (Khasrah-Bandobast).

The irrigation register (Shudkar-Khasrah) is divided into two parts, the *shudkar* for the initial record and the *khasrah* for the final record and measurement.

In this manner, it is assured that the patwari goes round at least twice through his allotted area (comprising several villages) in one crop. Were he to go round only once, the recording of a large number of fields would be omitted.

In order to avoid fraudulent concealment of irrigation or incorrect registration rules have been formulated regarding the manner of making entries in the register. The register itself has occasionally been modified to eliminate defects which have been discovered.

At present the *shudkar* entries comprise serial number, date of entry, field number, ownership and tenancy, date of sowing, crops sown, estimated area.

The area is entered in one of three columns provided for canal-irrigated, well-irrigated or rain-sown crops as the canal patwari at the present day makes all the crop entries in his allotted area.

In the *khasrah* are entered on the same line as the *shudkar* for the same field date of measurement, final measurement and area and other details connected with the preparation of the bills for the water used.

From these registers are prepared, after the measurement, the bills of each tenant for the amount of water used as assessed by his irrigated fields.

TIMES OF MEASUREMENT.

As crops come to maturity at varying seasons of the year, final measurements are recorded on four occasions during the crop year, April to March ; the first is recorded on June 1st for such crops as melons, tobacco, early fodders, the second on September 1st for cotton, sugarcane, millets, fodders, etc., the third on December 1st for rapeseed and turnips, and the fourth on February 1st for wheat and other cereals.

Bills are prepared and presented twice yearly.

The bills are presented to the tenants concerned and an abstracted copy is sent to the local treasury of the district through the officer of the Revenue Department responsible for the collection.

CHECK ON THE PATWARI'S WORK.

The work of the registrars of irrigation (patwaris) is constantly checked by a zilladar or revenue subordinate placed in charge of a section including about a dozen patwaris.

The zilladar also attends to the distribution of water, investigates complaints and generally sees that every cultivator gets his correct share of water. He is generally a man of ability and his work is of a responsible nature.

The Engineers also check the work of the registrars of irrigation to a small extent.

TRANSFERENCE TO CIVIL REVENUE OF THE RECORDING STAFF.

So far during the existence of the Irrigation Branch of the Public Works in the Punjab, the recording of irrigation, the assessment of the water-rate, and the preparation of the bills, that is, the work done by the staff of patwaris and zilladars has been subordinated to the Engineering Branch, but a proposal is contemplated by which the Civil Revenue Staff will undertake the recording, assessment and billing of the water-rate.

This is in order to reduce the number of officials. The method is being first tried on the Western Jumna Canal.

ASSESSMENT.

ASSESSMENT BY FIELD RECORD.

The method of assessment by field record of irrigation is one which ought to be very favourable to the cultivators.

The cultivators, however, complain that they are imposed upon by the registrar (patwari), and although perhaps there has never been a general feeling of animosity towards the patwari, the opinion is held that he tends to be a burden on the community.

Generally, the patwari and the cultivator agree with each other for the sake of mutual services rendered.

Such experience as the Engineers have obtained in the distribution of water has led to the development of a system in which the patwari interferes very little if at all in the distribution and consequently it rests with the cultivators or shareholders on an outlet to deal honestly by each other.

There are, however, weak and strong parties in every community and they are not absent among those who share an irrigation outlet, and the strong impose on the weak ones.

When the patwari had a hand in the distribution, as in the days during which periodic closure of outlets in distributaries was common, the patwaris had many opportunities of taking sides.

DISTRIBUTION BY TIME-SHARES.

It was noticed above that under the system of distribution by shares or turns in proportion to the areas of their holdings, the theoretical incentive to efficiency is the possibility for each cultivator to spread the water over as large an area as possible during his turn.

In spite of this theoretical incentive, it is known that there is considerable waste in the watercourse and in the field, which could be minimized or reduced if the shareholders on each outlet could realize better that carelessness in the use of the water was an offence more against the community than against the State.

The cultivating community do not realize the difficulties of the Engineering Staff and each cultivator simply looks to the Engineer to rectify his troubles whatever may be their origin.

They do not in the least appreciate the difficulty of constructing an accurate outlet, or one that will overcome the vagaries of their watercourses.

Each individual or each community simply asks for as much water as will be sufficient to swamp his field or their fields. They are individualistic to an extent which is difficult to realize.

In the cleaning and maintaining of watercourses, each individual does as little as possible, for why should his neighbour profit by his labour ?

The well maintained watercourses are not to be found in the villages but only on the properties of individual large landowners.

PAYMENT BY VOLUME.

The Irrigation Engineer in the Punjab has always visualized the introduction of a system of payment for water in proportion to the volume received.

The object of such a system is the increase which follows in the efficiency of the irrigating machine by the creation of an incentive to utilize but the minimum quantity of water.

There would also be the release of the large and expensive staff of patwaris.

For such a system to be effective each individual must feel that his efforts at efficient use of the water will be rewarded ; unless this direct individual incentive is created, there is but little hope of success for any scheme of volumetric assessment. These may have an experimental value and be interesting to that degree.

A scheme of individual supply as outlined above has not so far been considered practicable on account of the large number of meters that would be required.

But it is possible to contemplate a modification thereof if several adjacent farmers who could rely on each other would club together and have a meter between them.

Another step and we arrive at a scheme where the meter is placed on the watercourse as it issues from the distributary, that is, the outlet is the meter.

The outlet is in a manner of speaking a unit in the system of distribution. So far, in the distribution of water as practised in the Punjab, the aim is to give a group of cultivators at the

outlet a supply, which, as far as the department is concerned, is a measured supply.

There has not been from the cultivators any universal attempt at association with the department even to the extent of understanding what volume was due to them at the outlet.

If the cultivators educated themselves to the extent of understanding that, they would perhaps ask for a metered supply.

ATTEMPTS AT VOLUMETRIC SUPPLY.

The attempts so far made to introduce volumetric assessment have consisted in making contracts to supply large landowners with their requisite discharge and charging them at a rate per cusec per day. The supply is measured as it enters the watercourse from the distributary.

Large watercourses or minor distributaries have been the channels of supply under such contracts.

It is stated that these contracts have been entered into by the parties in the hopes of preferential treatment as regards their water allowance.

This spirit is quite the reverse of that required for the success of volumetric assessment.

In fact, the amounts paid by the contracting parties under the volumetric assessment has been more than what they would have paid under an assessment by acreage.

This, in spite of the fact that the rate per day cusec, *viz.*, Rs. 2-8-0 in the Kharif and Rs. 5-0-0 in the Rabi is a lesser rate than has been calculated from the statistics available, and there has not been any economy in the use of water.

The large landowner generally recovers from his tenants rent and other dues *in kind.*

The tenants under the scheme attempted have not had any inducement to economize.

The recovery of the water-rate from the large landowner has been an easy matter.

It is not certain that were a measured supply given to a group of cultivators on an outlet, that the group would possess sufficient cohesion to act as a syndicate.

Evidently, the first steps in such a transaction would need to come from the syndicate.

COLONIZATION.

THE SQUARE SYSTEM.

To facilitate the recording of irrigation done in the Punjab, it was decided when the areas of crown waste-land on the Sidhnai Canal and the Lower Chenab were made available for colonization, that these areas would be divided up into squares.

There were some 400 square miles of crown waste on the Sidhnai and 3,500 square miles on the Lower Chenab. To accord with the local land measure the squares were of sides 1,100 feet long and consequently of area 27·78 acres. A twenty-fifth part of each square is a field of $1\frac{1}{9}$ acres. Subsequent to the laying out of the squares it was decided to lay out the field as well.

This proposal was first evolved in connection with the scheme for the colonization of the tract to be served by the Chenab Canal, but it was first applied to the tract irrigated by the Sidhnai Canal.

This sub-division into squares and fields has been of great practical value. The records of irrigation are promptly and accurately collected, the bills for the water supplied are rapidly prepared and the chances of error are much reduced.

Maps of the localities are quickly prepared, a matter of some importance, when it is considered that every application in connection with water supply or distribution sent in by cultivators has generally to be accompanied by a plan of the locality referred to.

In other countries, surveyors at some expense would have to be employed repeatedly.

On the Sidhnai Canal a base line was laid in each village and from this the squares were laid out.

Later, on the Chenab and Jhelum Canal one base line was laid out for the whole canal.

The boundaries of villages were made to coincide with the alignments of canals and distributaries and as far as possible one watercourse was allowed to the shareholders of one village. These are valuable details in the distribution of water, as shareholders belonging to one village community are more likely to be in agreement over the distribution of water. Comparison can be made with the Sirhind Canal, for instance, which is aligned through old proprietary villages ; the distributaries run through the areas of villages and generally cut them up so that the areas of the villages on each side are too small to be allowed one separate outlet each.

Then, parts of several villages have to be collected in twos and threes on a common outlet and watercourse ; these amalgamations are seldom popular. Occasionally a watercourse on such a system will be made to irrigate two parts of a village lying on both sides of a distributary through a syphon under the distributary channel.

These troublesome details are avoided with the square system.

As a later development instead of squares, the country is now divided up into rectangles, the dimensions being 1100′ × 990′ exactly 25 acres in area. Each field is therefore 1 acre in extent. On the land in the proprietary villages adjacent to the colony lands on the colony canals, the square system has also been introduced, the irregular boundaries of the old properties having been made to coincide as closely as possible with the sub-divisions of the squares by some give and take.

APPENDIX.

DIAGRAM TO ILLUSTRATE THE DISTRIBUTION OF THE STAFF ON AN IRRIGATION CANAL.

For the purpose of Works Construction and Maintenance.

Superintending Engineer

Executive Engineer, A Division | Executive Engineer, B Division | Executive Engineer, C Division

Sub-Divisional Officer | Sub-Divisional Officer | Sub-divisional Officer.

Section Holder | Section Holder | Section Holder.

Artizans | Labourers | Petty Contractors.

For the purpose of water distribution and assessment of revenue, the Sub-Divisional Officer has a revenue staff as shown in diagram below, and the Executive Engineer has a special assistant known as a Deputy Collector.

Sub-Divisional Officer.

Zilladar, G section | Zilladar, H section | Zilladar, K section

ach zilladar has 10 or 12 patwaris.

APPENDIX.

CLASSIFICATION OF IRRIGATION WORKS FOR PURPOSE OF ACCOUNTS.*

1. For purposes of accounting, Irrigation Works are classified into Major and Minor Works. The Major Works are again sub-divided into Protective and Productive Public Works; while the sub-classification of the Minor Works consists of (1) works for which the Capital and Revenue Accounts are kept, (2) works for which only Revenue Accounts are kept, and (3) works for which neither Capital nor Revenue Accounts are kept. Capital and Revenue Accounts are maintained for the more important Minor Works, but for those on which the capital outlay has not exceeded half a lakh of rupees, Revenue Accounts only are, as a rule, maintained.

2. Protective Works are those which are not directly remunerative to the extent which would justify their inclusion in the class of Productive Works, but which are constructed with a view to the protection of tracts in which rainfall is precarious in order to guard against the necessity for periodic expenditure on the relief of the population in times of famine. The cost of these works is a charge against the current revenues, and is generally met from the annual grant for famine relief and insurance. There are no such works in the Punjab.

3. Productive Public Works are works of a remunerative character, undertaken either for the purposes of navigation or in the interests of general agricultural development of the country; and both their first cost and any subsequent expenditure on extensions and improvements are met from borrowed capital. The charges for interest and for maintenance and repairs are provided for out of current revenues, to which is credited income derived from these works. Such works are expected, within ten years after the probable date of the completion, to yield sufficient revenue to pay their working expenses and the annual interest calculated at 4 per cent. on the capital invested.

4. There are only two Minor Works, *viz.*, the Shahpur Imperial Inundation Canals and the Ghaggar Canals for which Capital and Revenue Accounts are kept. The former irrigate the Shahpur District while the latter water portions of the Hissar District and Bikaner State.

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* From the Administration Report for 1919-20.

5. The Minor Works, for which only Revenue Accounts are kept, are (1) the Lower Sutlej Inundation Canals, including the Hajiwah Canal, (2) the Chenab Inundation Canals and (3) the Muzaffargarh inundation Canals. The former two sets of canals irrigate the Multan District, whereas the latter are situated in the Muzaffargarh District.

6. There is one other group of Provincial Canals, the Shahpur Provincial Inundation Canals, which also irrigate the Shahpur District. The cost of these is borne entirely by the Provincial Government.

7. Of the Minor Works, for which neither Capital nor Revenue Accounts are kept, one, known as the Muzaffargarh Embankment, is imperial, and the expenditure on it is met from current revenue ; while the following three canals are Provincial :—

(1) Gurgaon Bunds.

(2) Namal-Dam and Canal.

(3) Kitchin-Irving Canal.

These Provincial Canals are controlled by the Civil Revenue authorities, under the Punjab Minor Canals, Act III of 1905.

8. Surveys and other preliminary investigations in connection with irrigation and drainage projects for Productive Public Works are also treated as works for which neither Capital nor Revenue Accounts are kept ; the cost of these surveys, etc. being met from Provincial revenues ; but after the projects are sanctioned by competent authority, all this expenditure is charged to the sanctioned projects estimate.